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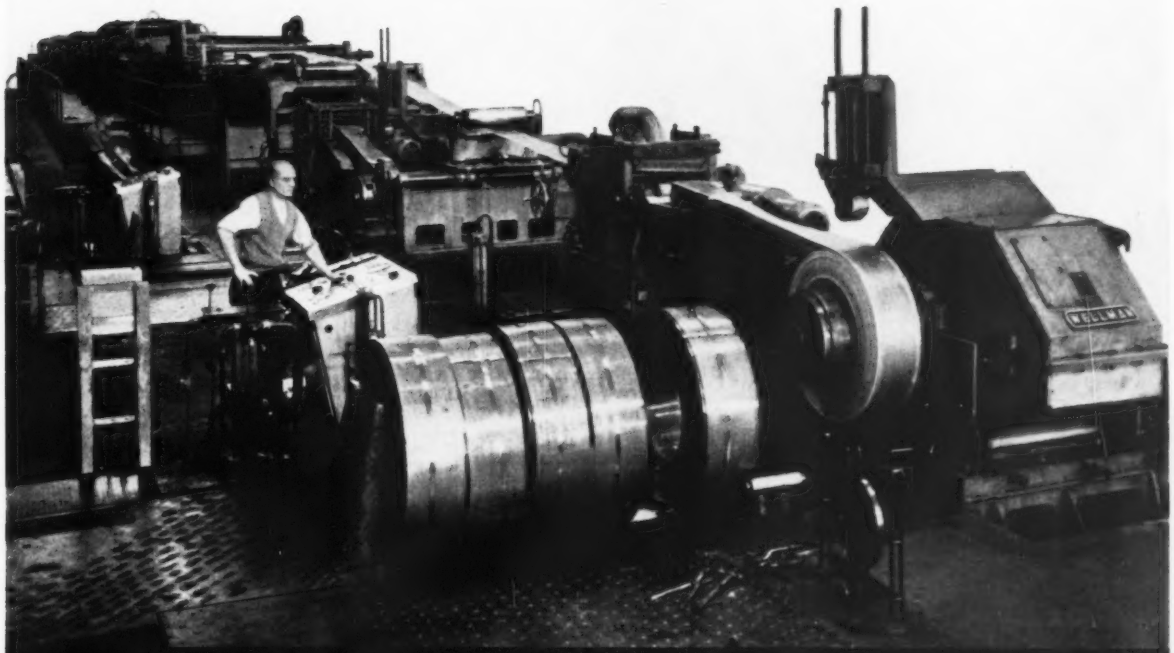

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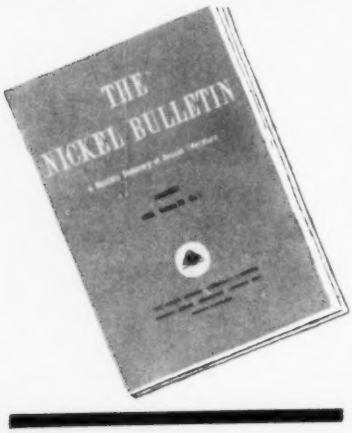

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Top—A Holmes-Elex Electrical Precipitator cleaning exhaust air from the collecting hood enclosing the Scarfing Plant at the Corby Works of Messrs. Stewarts & Lloyds Limited.

BLAST FURNACE GAS CLEANING

Left—A two-section Holmes-Elex Electrical Precipitator installed for the final cleaning of blast furnace gas at the Scunthorpe Works of the Appleby-Frodingham Steel Company (Branch of the United Steel Companies Limited).

BLAST FURNACE GAS CLEANING

Right—Three irrigated Holmes-Elex Electrical Precipitators preceded by Wash Towers cleaning blast furnace gas at the Bilston Works of Messrs. Stewarts & Lloyds Limited.

FERRO-MANGANESE GAS CLEANING

Bottom—Three Holmes-Elex Electrical Precipitators cleaning ferro-manganese gas after the blast furnaces at the works of the Workington Iron & Steel Company (Branch of the United Steel Companies Limited).

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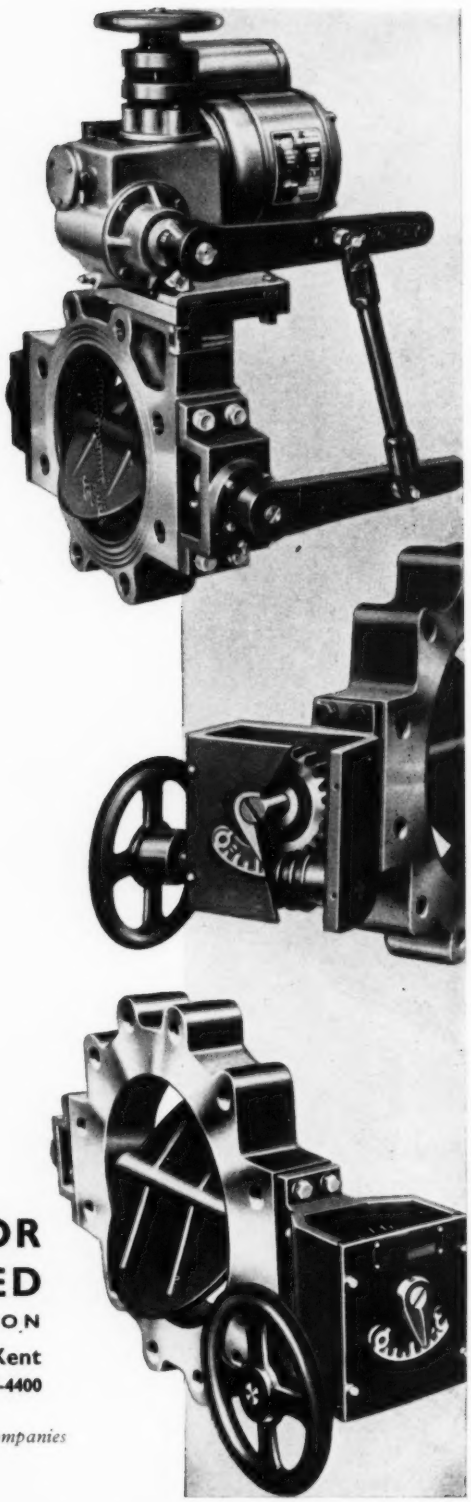

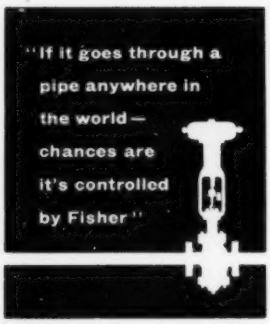

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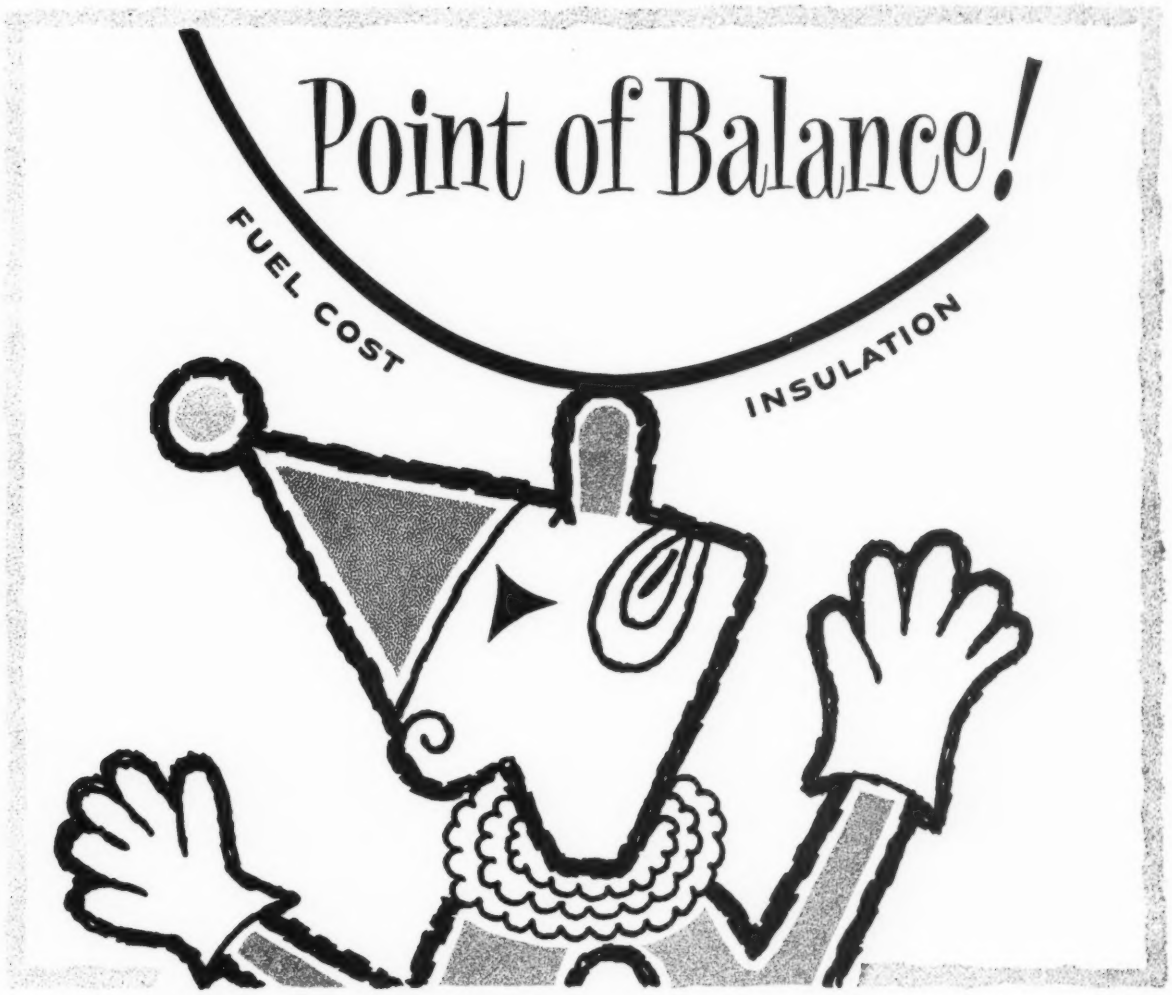

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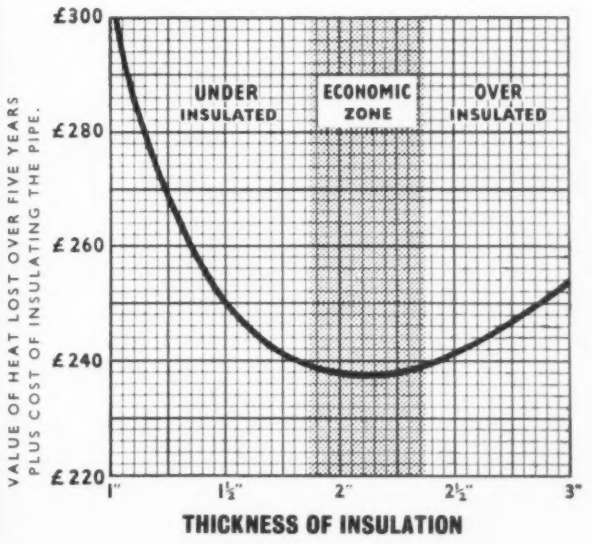

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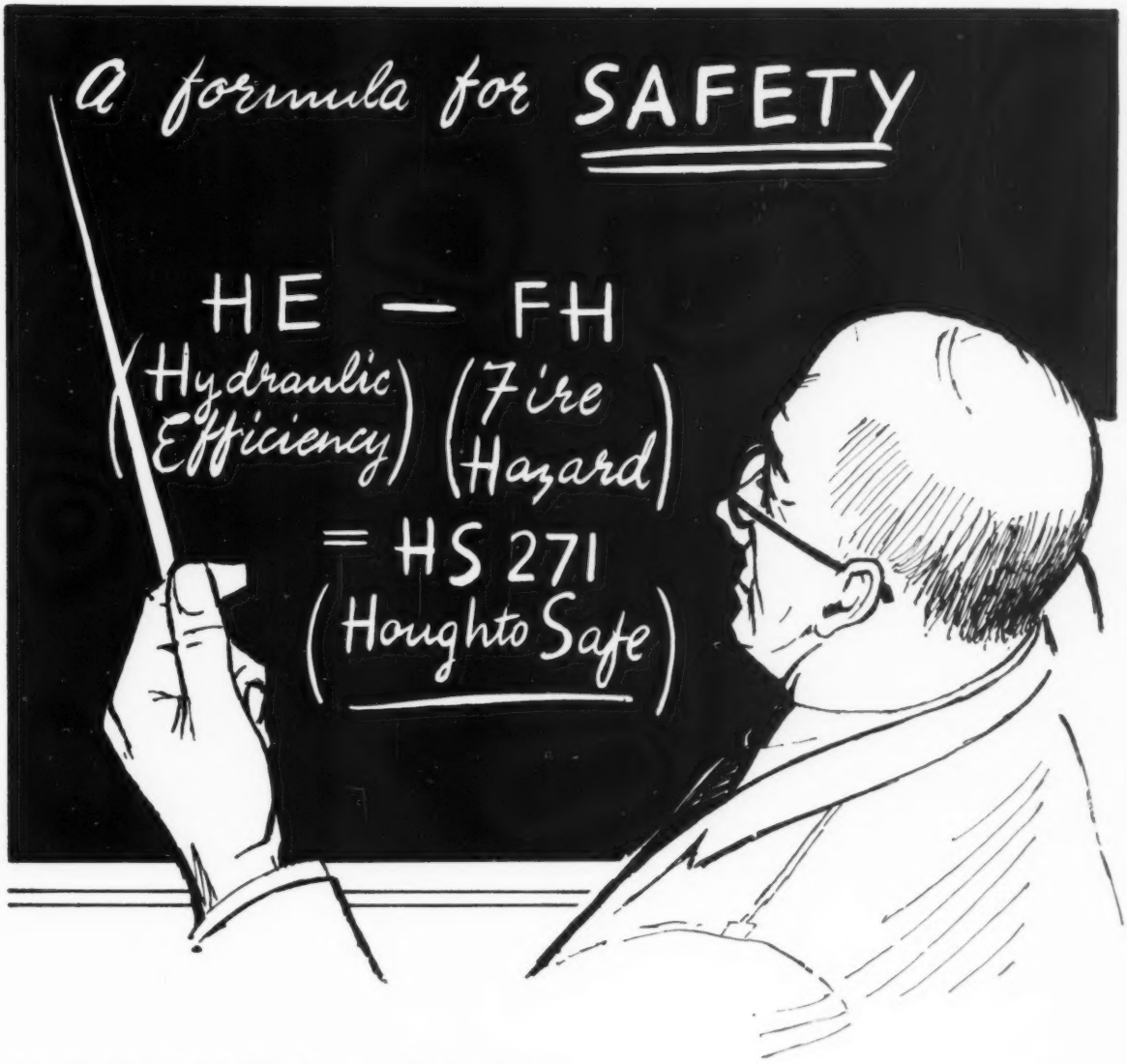

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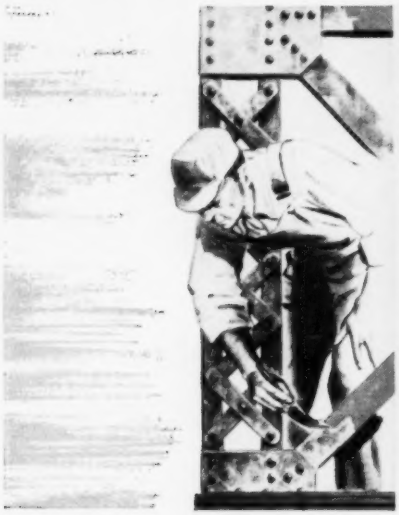

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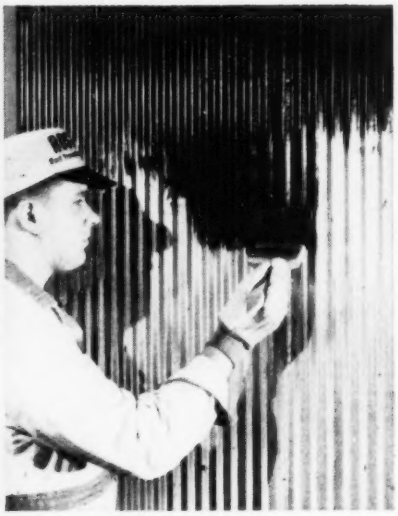

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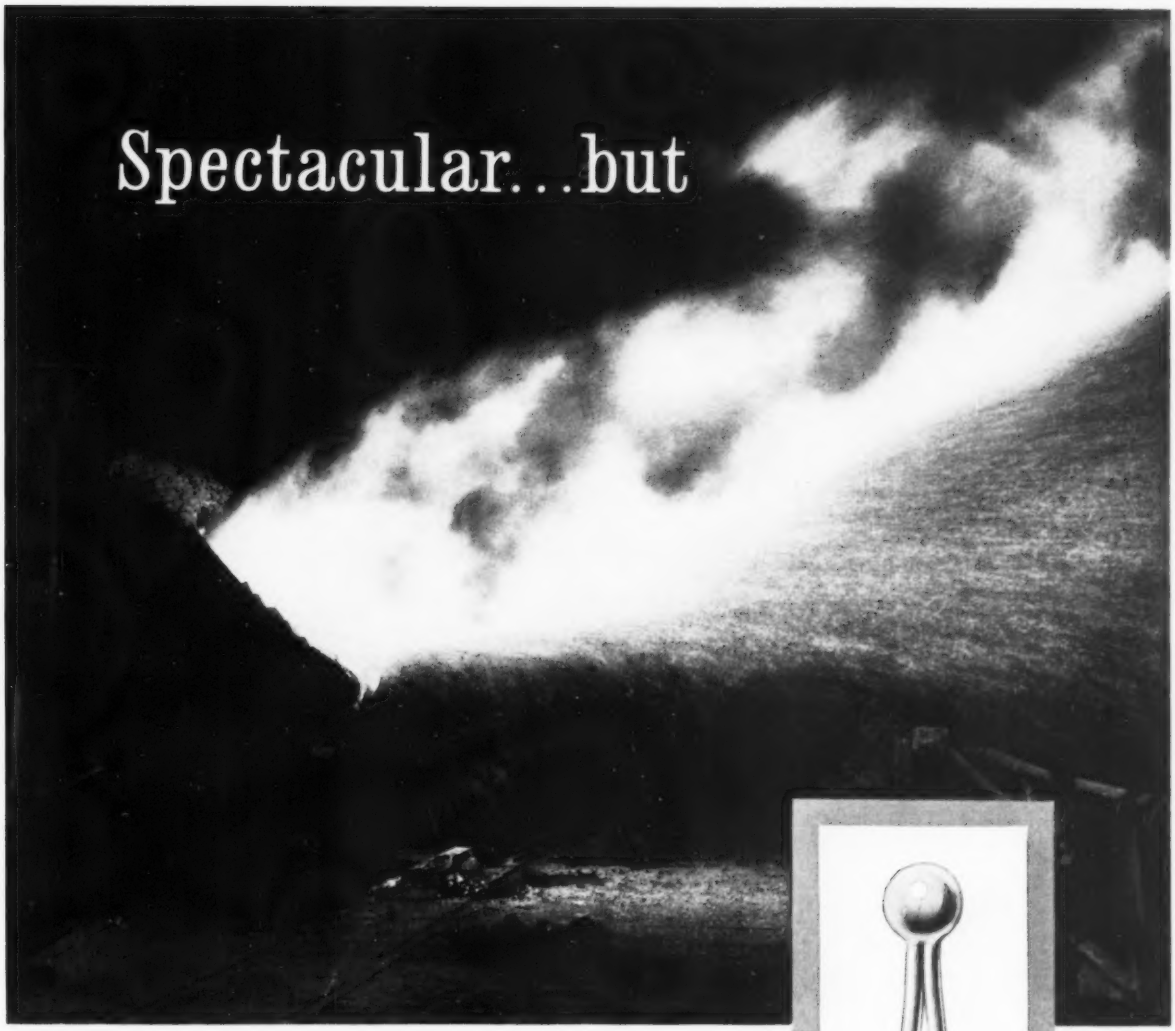

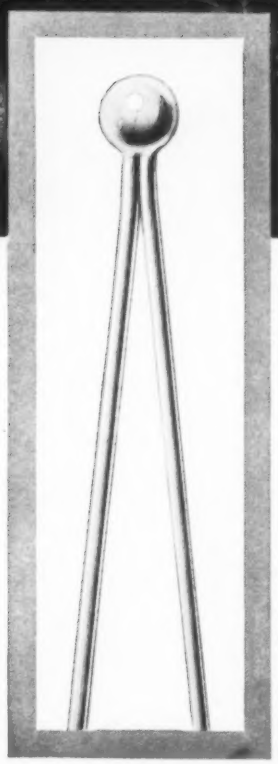

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Most modern soluble cutting oils contain phenolic compounds used as coupling agents between the oil and the emulsifier, for better blending and easier mixing. These phenolic compounds can cause skin irritation, especially where modern high-speed machines are used and the emulsion can concentrate, through the evaporation of water, above the safety level.

Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, the Shell range of Dromus Oils has been reformulated and these new cutting oils, now bland, considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the pleasant position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors to produce the right oil for the job. If you and your organization have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

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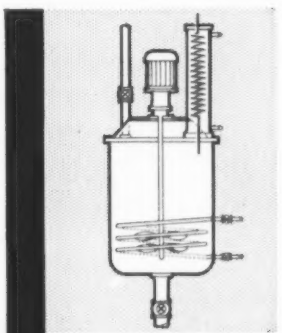

This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.

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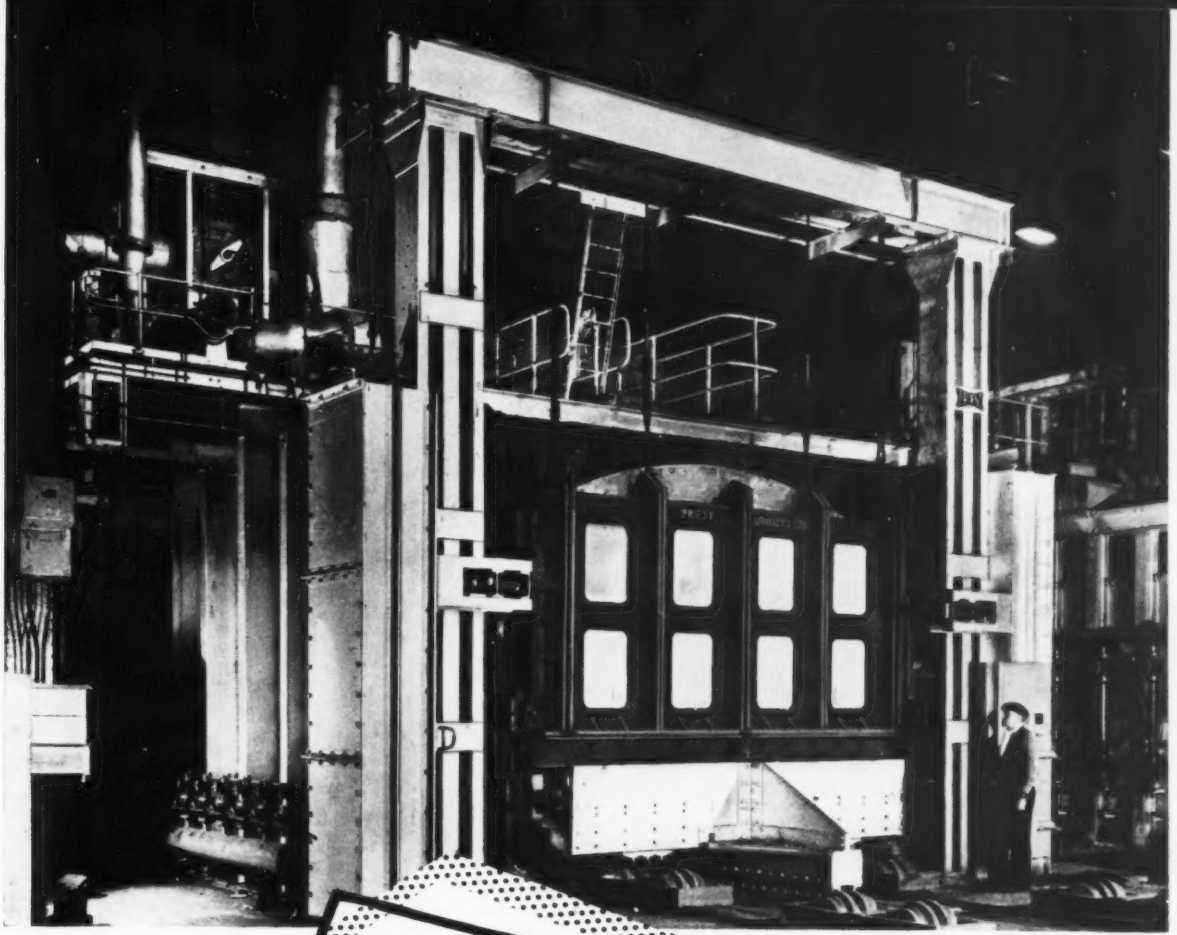

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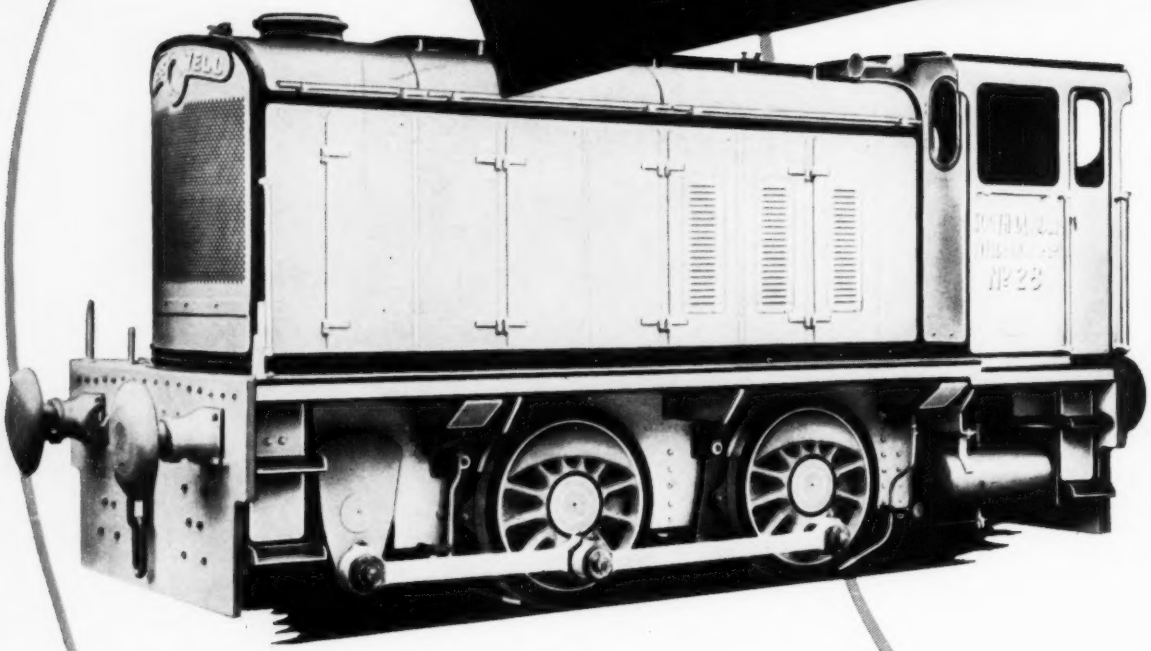

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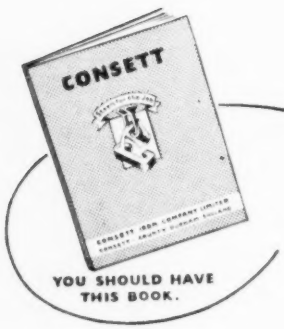

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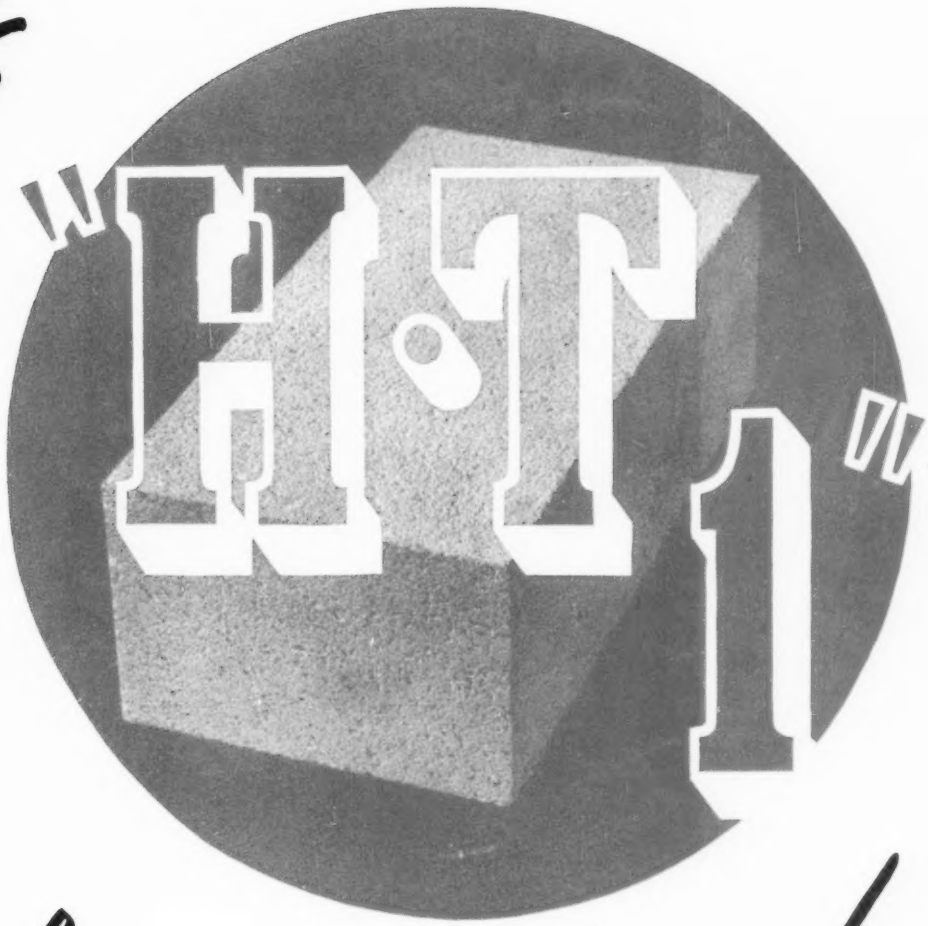

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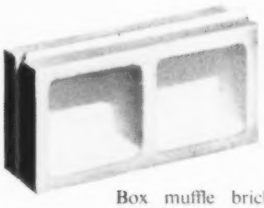
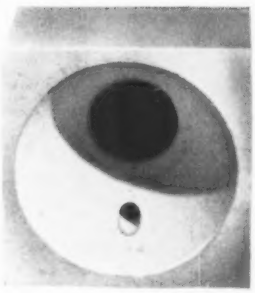
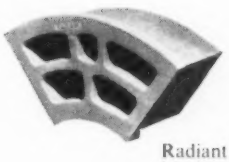


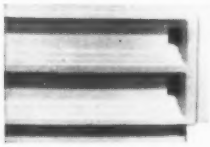
Box muffle bricks for heat-treatment furnaces.



Burner block



Radiant heater block.



Electrical resistor tile.

APPLICATIONS

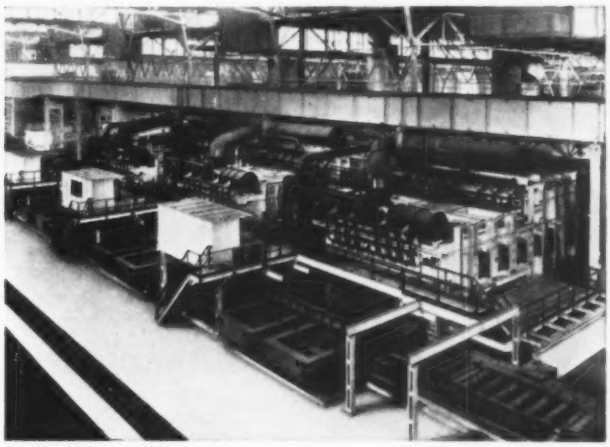
Combustion Chambers and fireboxes · Burner Blocks
Gas Port Blocks · Burner Baffles · Hearth Tiles · Sidewalls
Roofs · Hot repair Tiles

BRASSINGTON

SEMI-SILICA BRICKS SHAPES AND CEMENTS

The Swann Brassington semi-silica brick is prepared by blending specially hand picked sand from the Company's extensive deposits with a small amount of Devon Ball clay, thereby ensuring a consistent product with a minimum amount of impurity.

Semi-silica bricks are characterised by a considerably higher resistance to thermal shock than normal silica bricks, volume stability, and a tendency to glaze in service. When used in conjunction with Swann Brassington siliceous cement, the bricks and cement glaze together forming a monolithic structure. Failure due to joint erosion is therefore eliminated. The bricks have a high resistance to erosion by slag attack and to abrasion by dust-laden furnace gases.



Complete battery of soaking pits all lined with Brassington Semi-Silica Bricks. With acknowledgements to Stein & Atkinson Ltd.

APPLICATIONS

Reheating Furnaces, Complete Linings
Soaking Pits, Complete Linings
Construction of Slag Pocket Arches
Construction of Stoker Arches
Side Walls of Combustion Chambers, Complete
Furnace Door Linings
Complete Open Hearth Furnace Regenerator Systems

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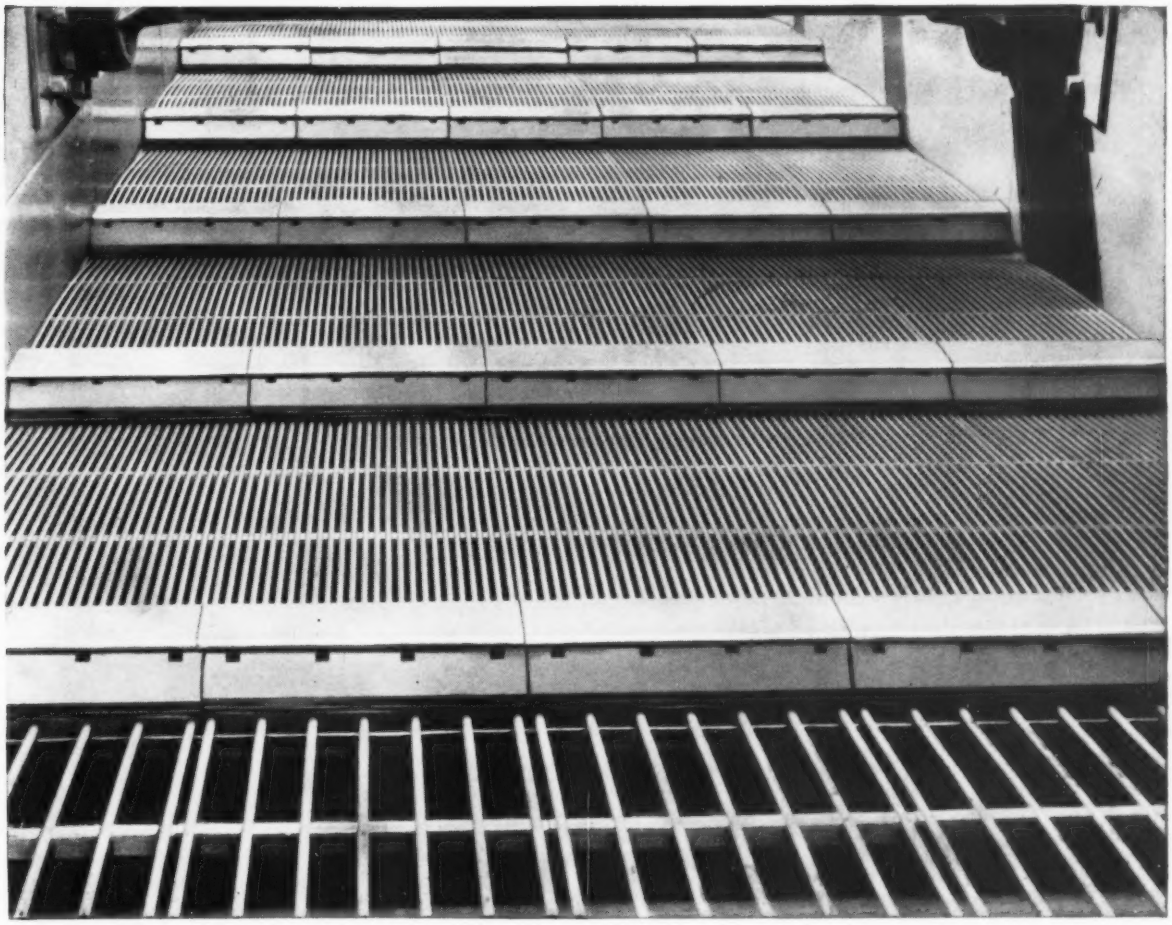

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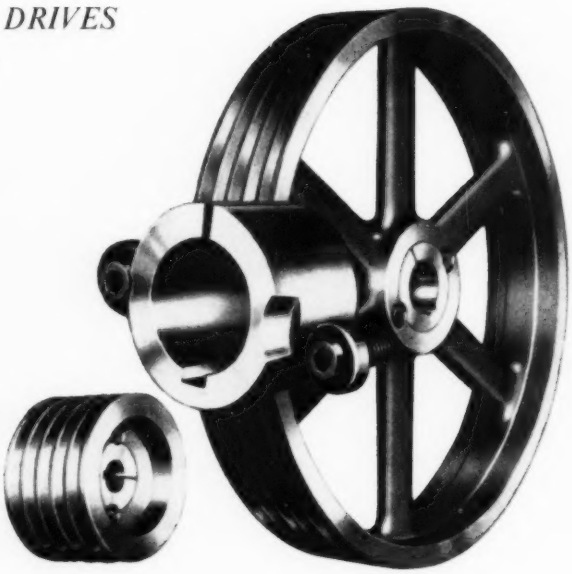

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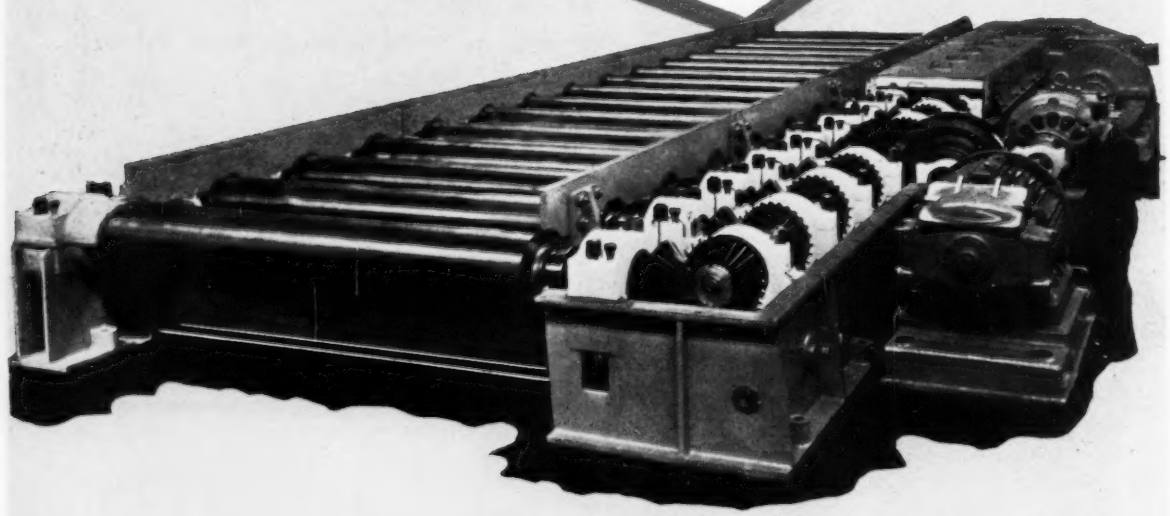

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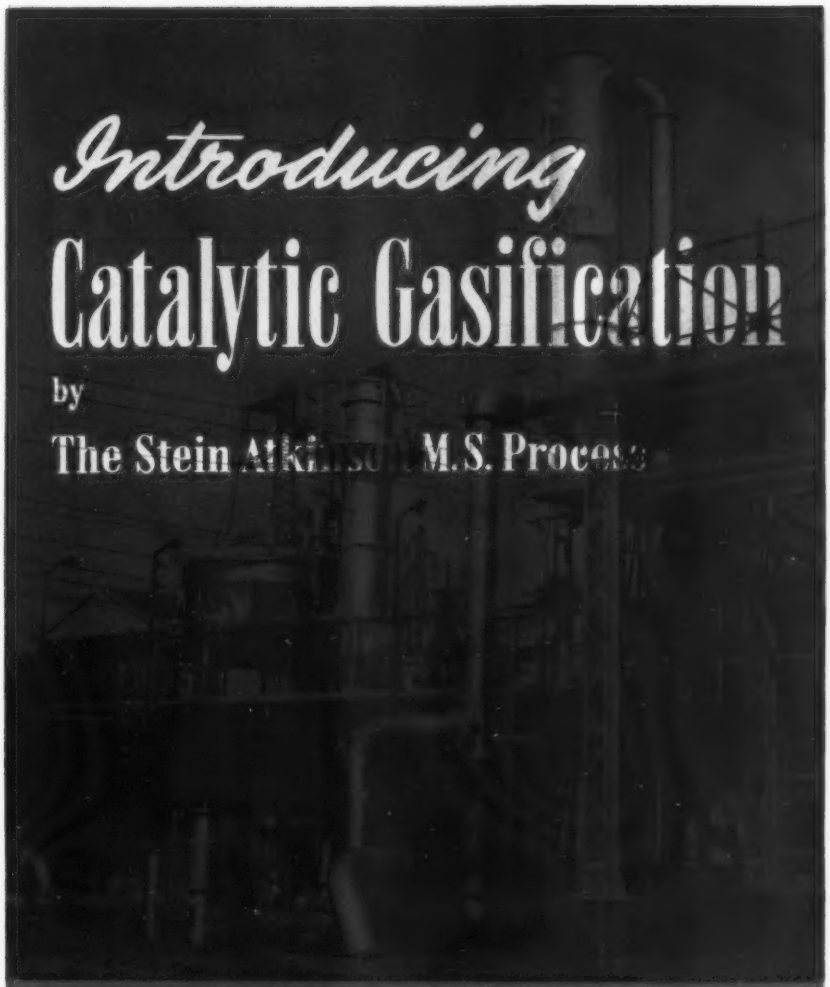

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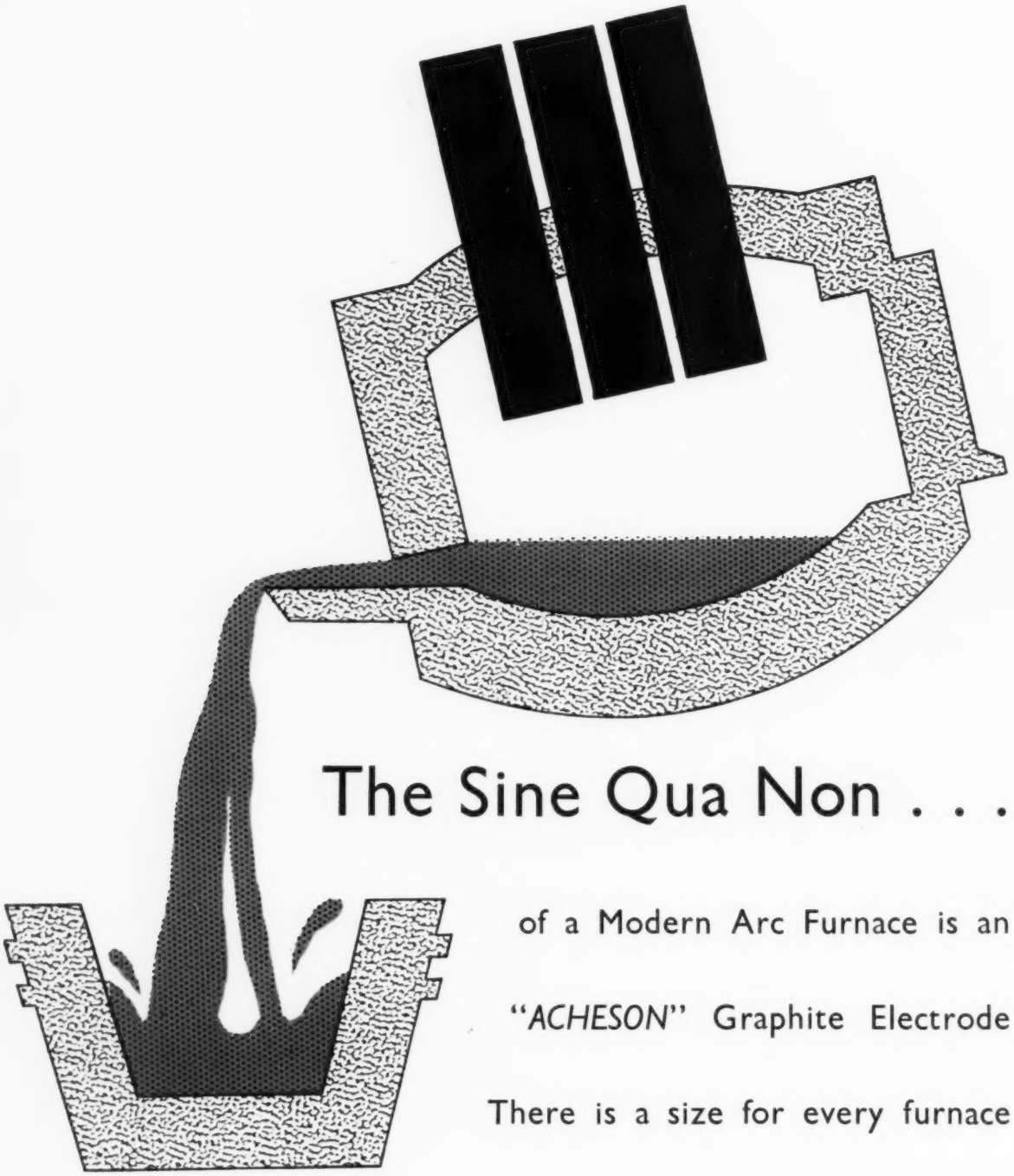

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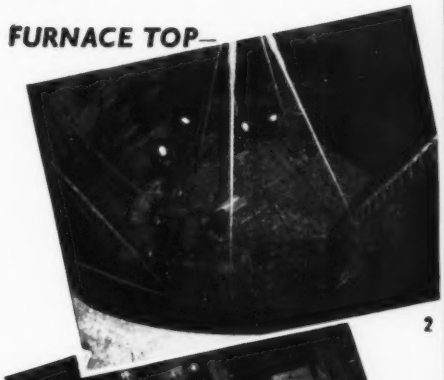

2

3

4

—TO FURNACE BOTTOM

1 *'Lumpy going'—half-way down hearth.*

2 *Men removing throat armour.*

3 *Cat Traxcavator commencing, digging, Cast House Floor Level.*

4 *The two 'Cats' meet, final 'break through'.*

Scenes of operations at No. 1 Blast Furnace 1
(photos by permission of John Summers & Sons Ltd., Shotton)

TOTAL TIME wrecking burden, lining, hearth and bear 18 **DAYS.**
(contract carried out in association with Salem Engineering Co., Ltd.)

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Demolition commenced 7th August, 1959
Demolition completed 21st August, 1959

TOTAL TIME wrecking burden, lining hearth and bear 14½ **DAYS.**

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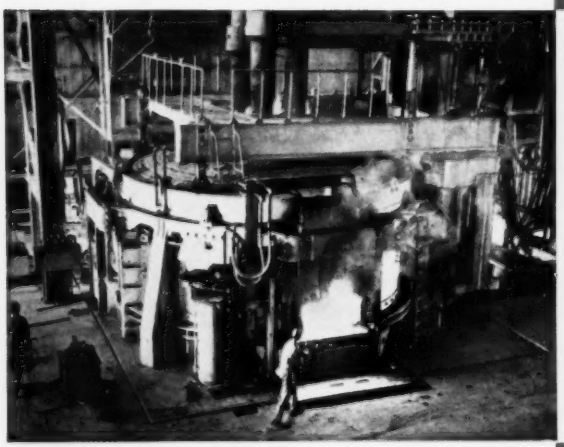
Lectromelt 36,000 kVA Steel Melting Arc Furnace with 24' 0" diameter shell



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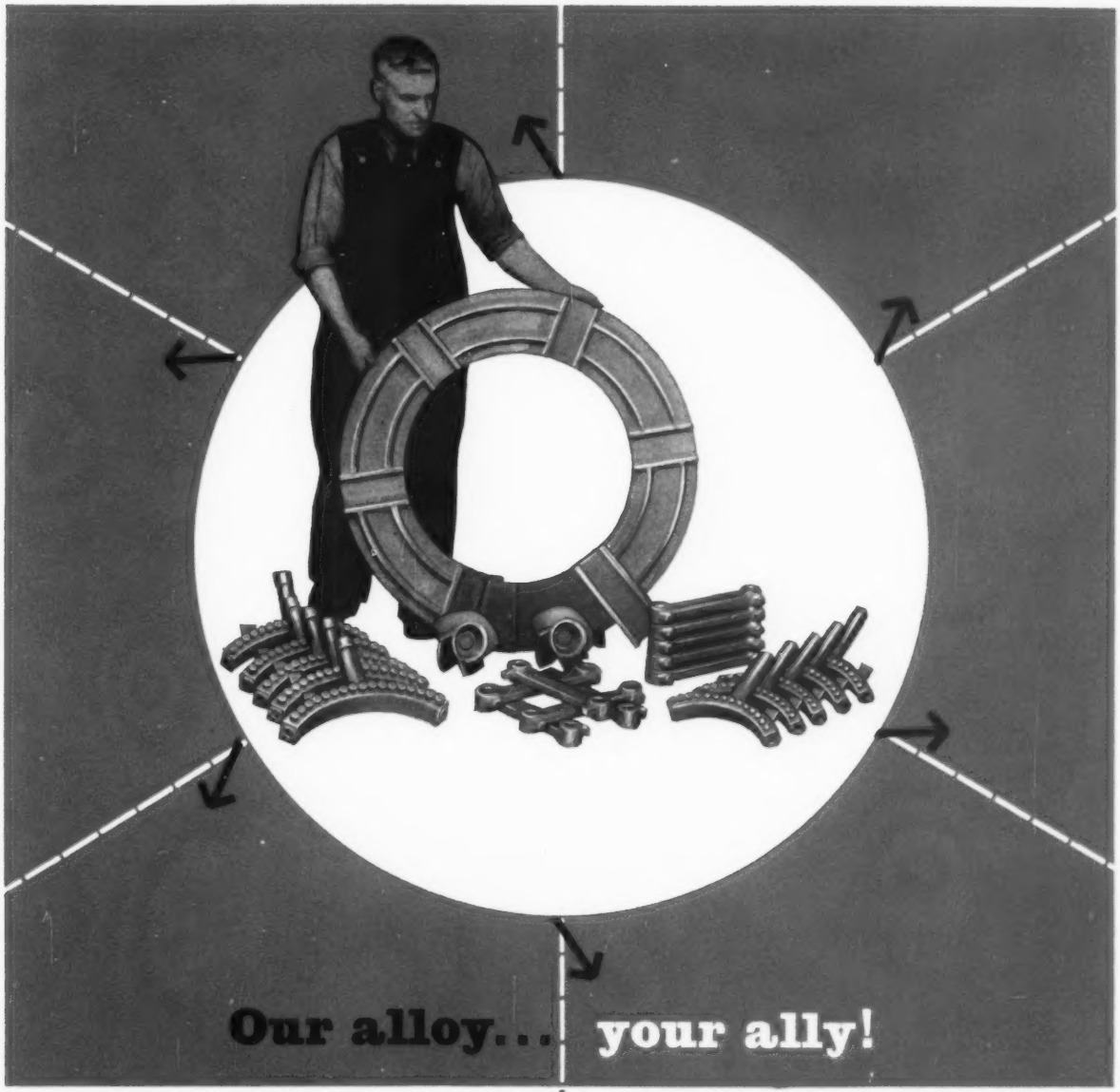

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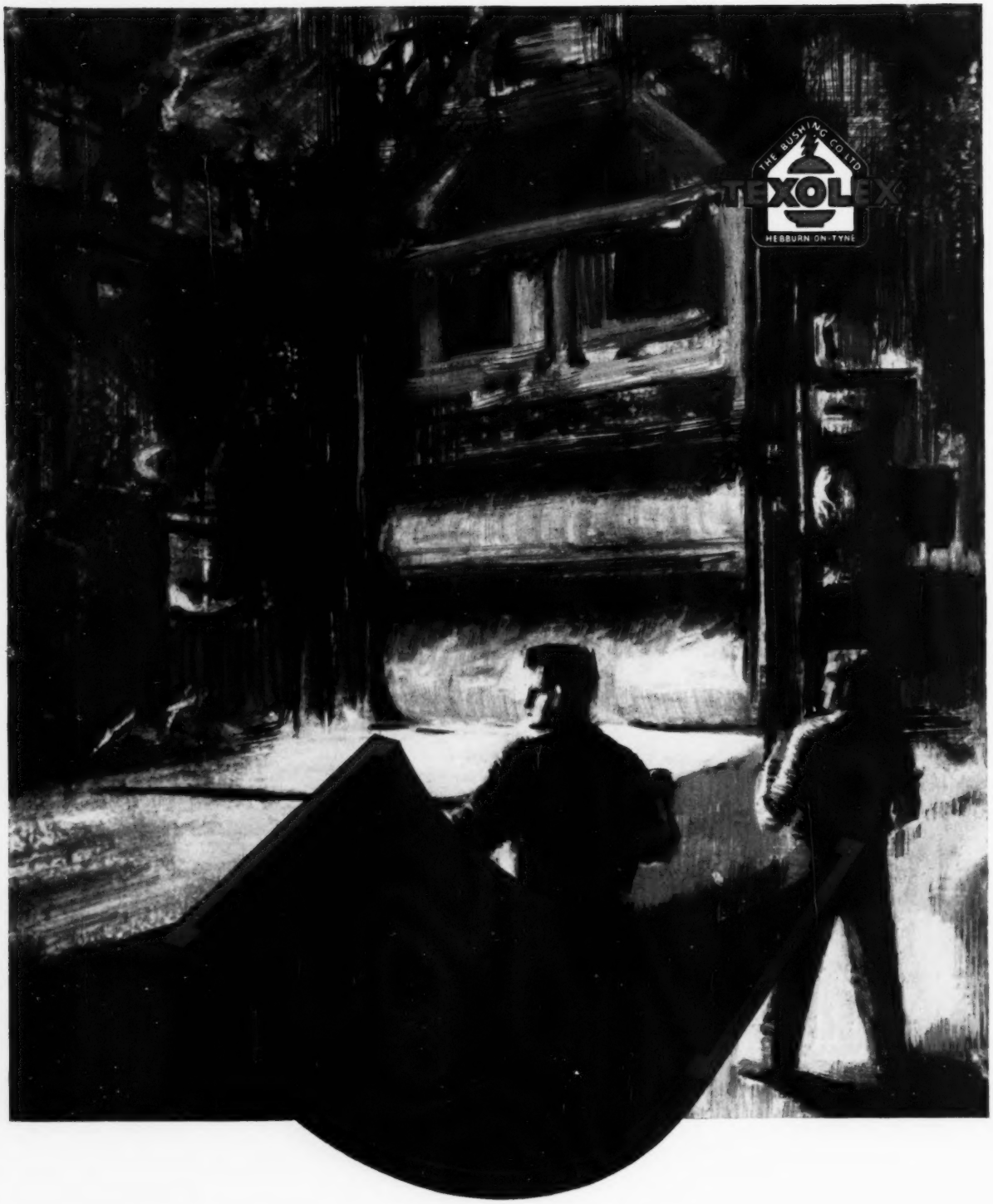

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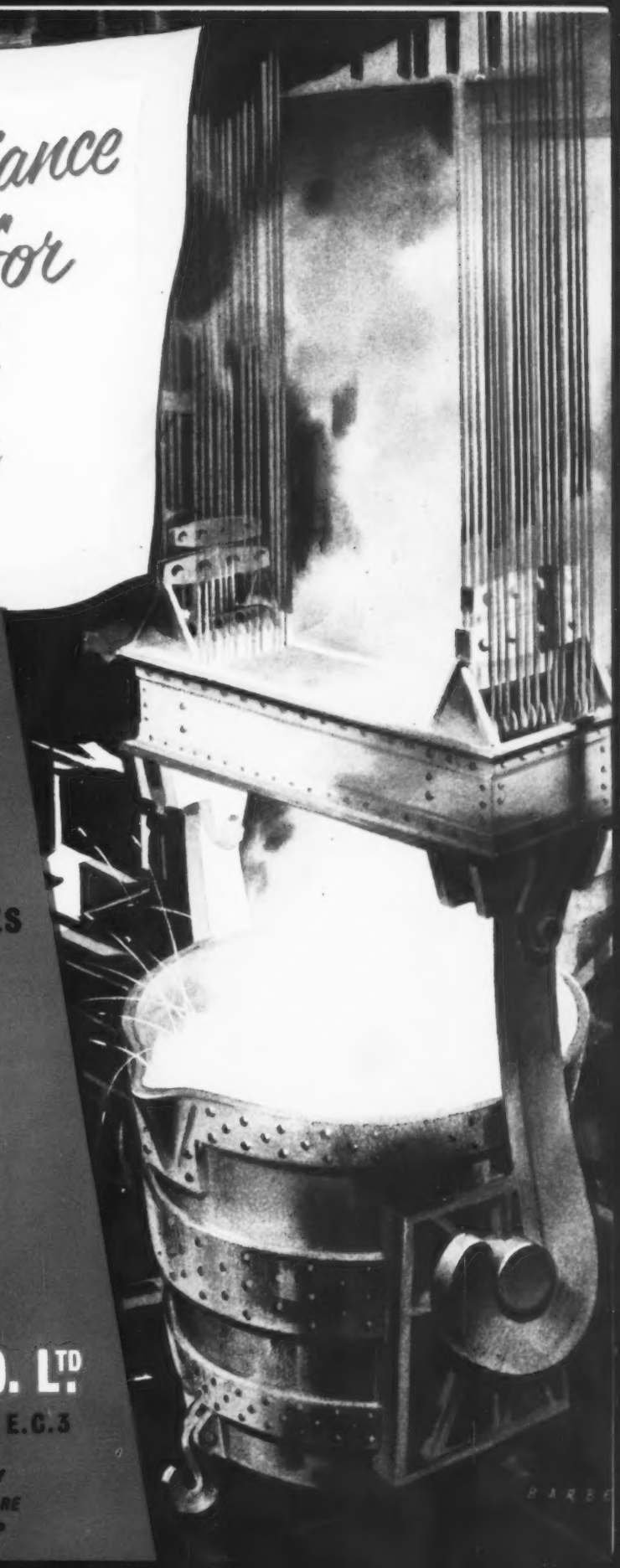

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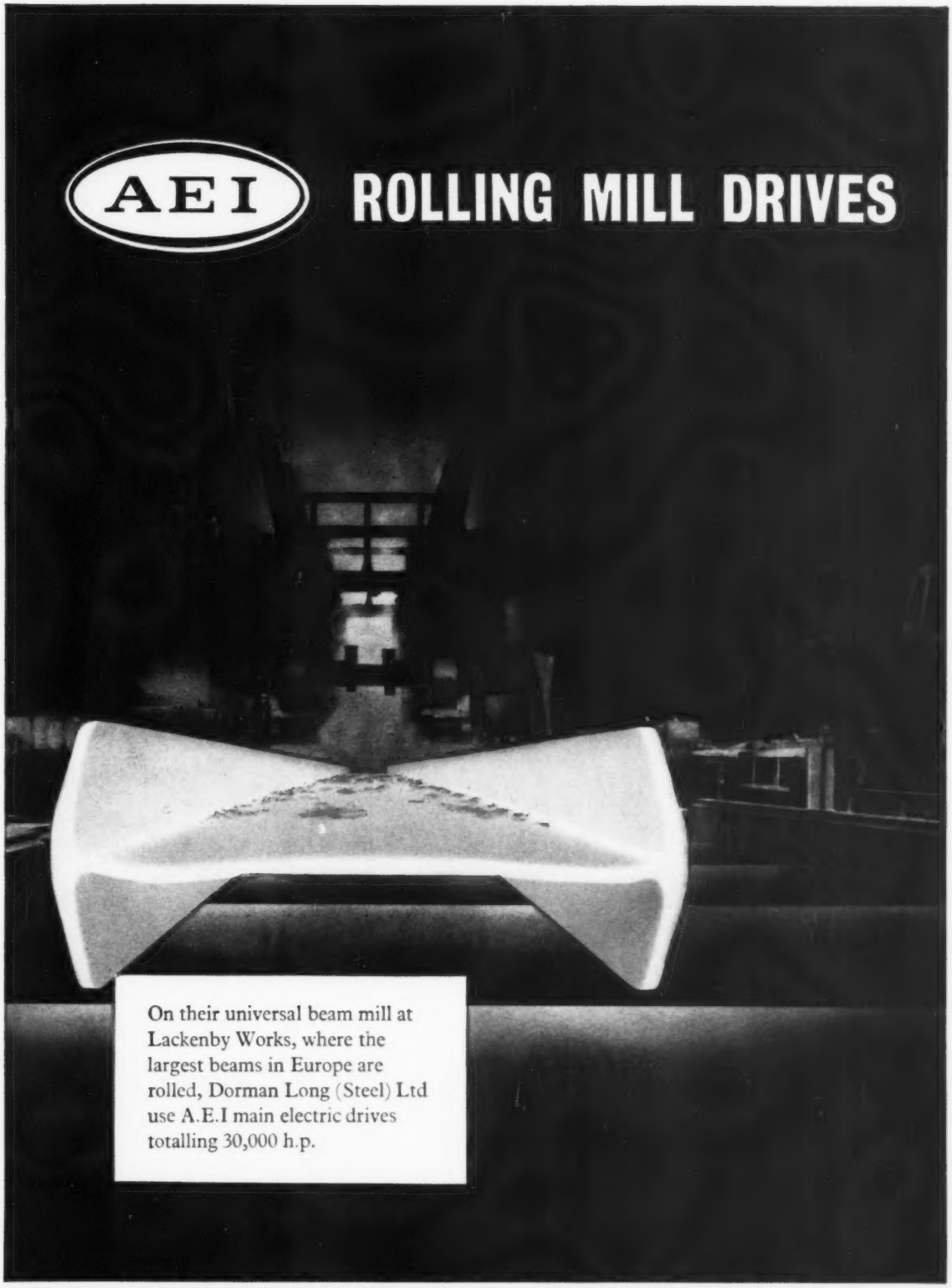

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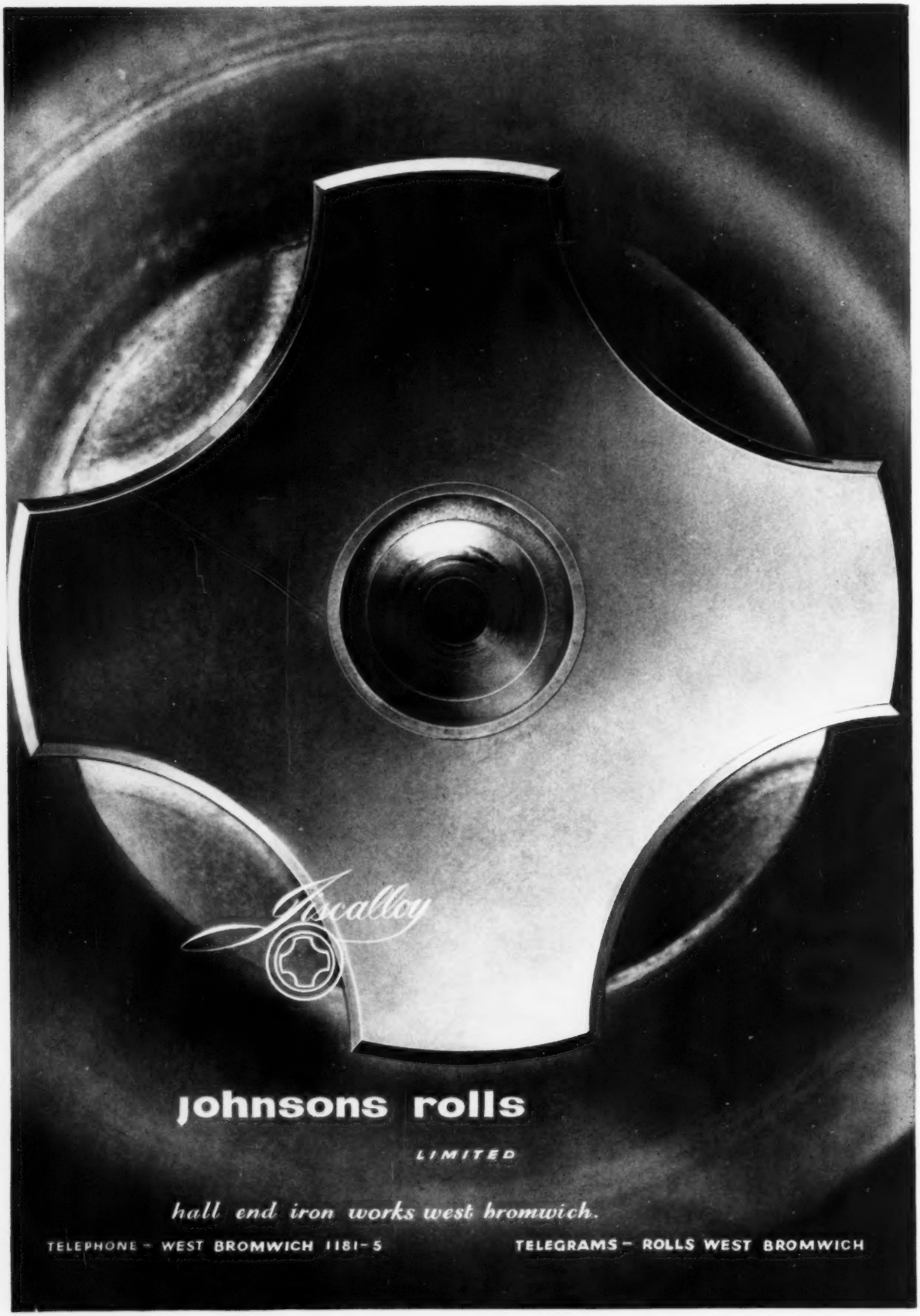
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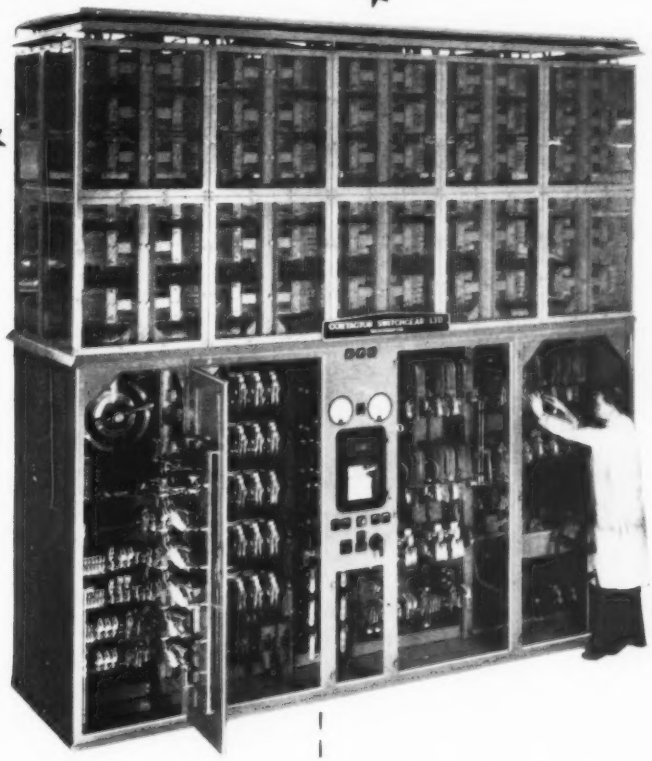

The photograph shows a 2,300 H.P. 600 volts D.C. Shunt (Stability Compounded) motor control panel incorporating a motorised preset shunt field regulator, 'inch forward', 'inch reverse' features and emergency sustained dynamic braking for a "Cross Country" steel rod mill.

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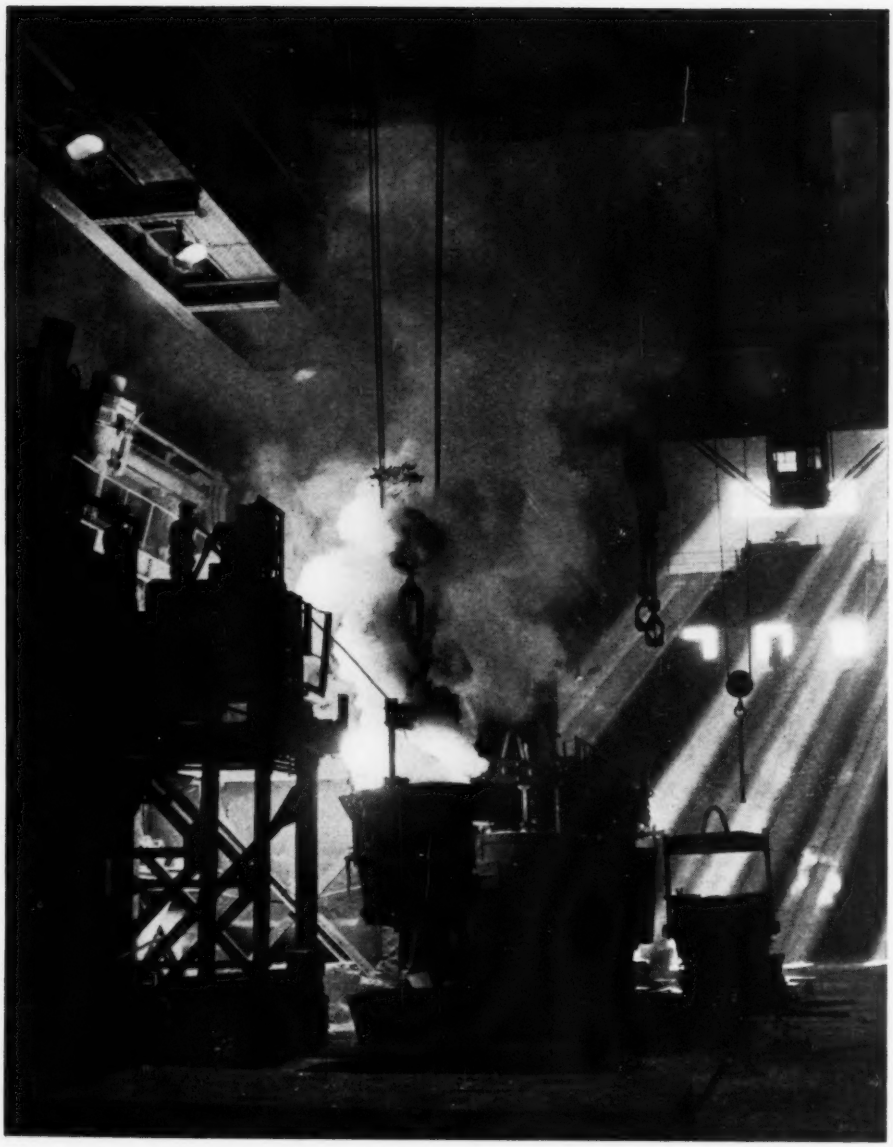

Furnace tapping in the Electric Arc Melting Shop of Messrs Thos Firth & John Brown Ltd Sheffield, by whose courtesy this photograph is reproduced

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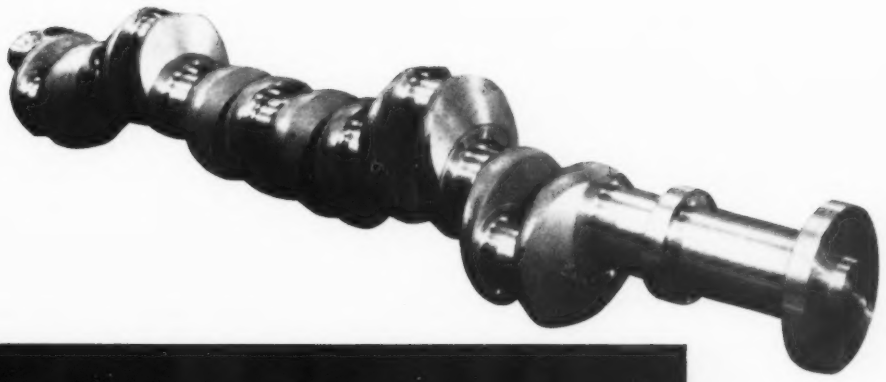

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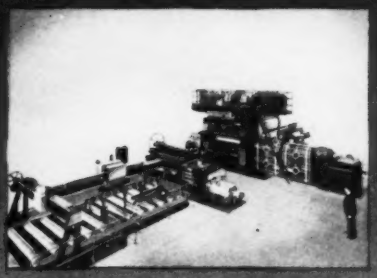

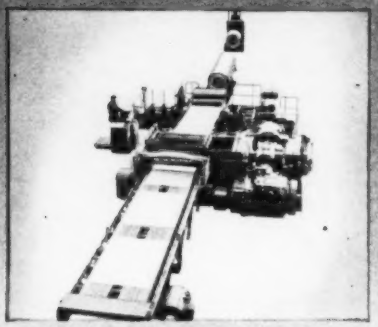

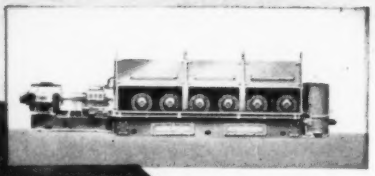

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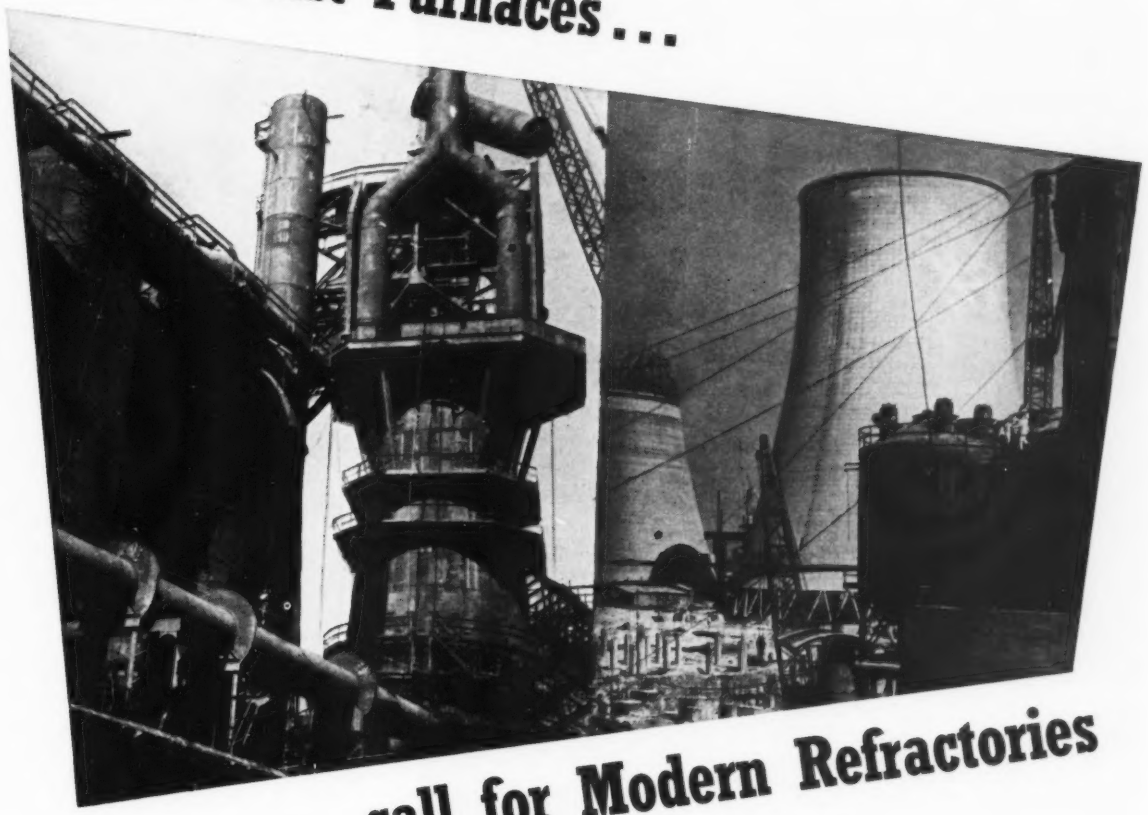

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Improved 42% Alumina refractory for use in lower stack, bosh and hearth.

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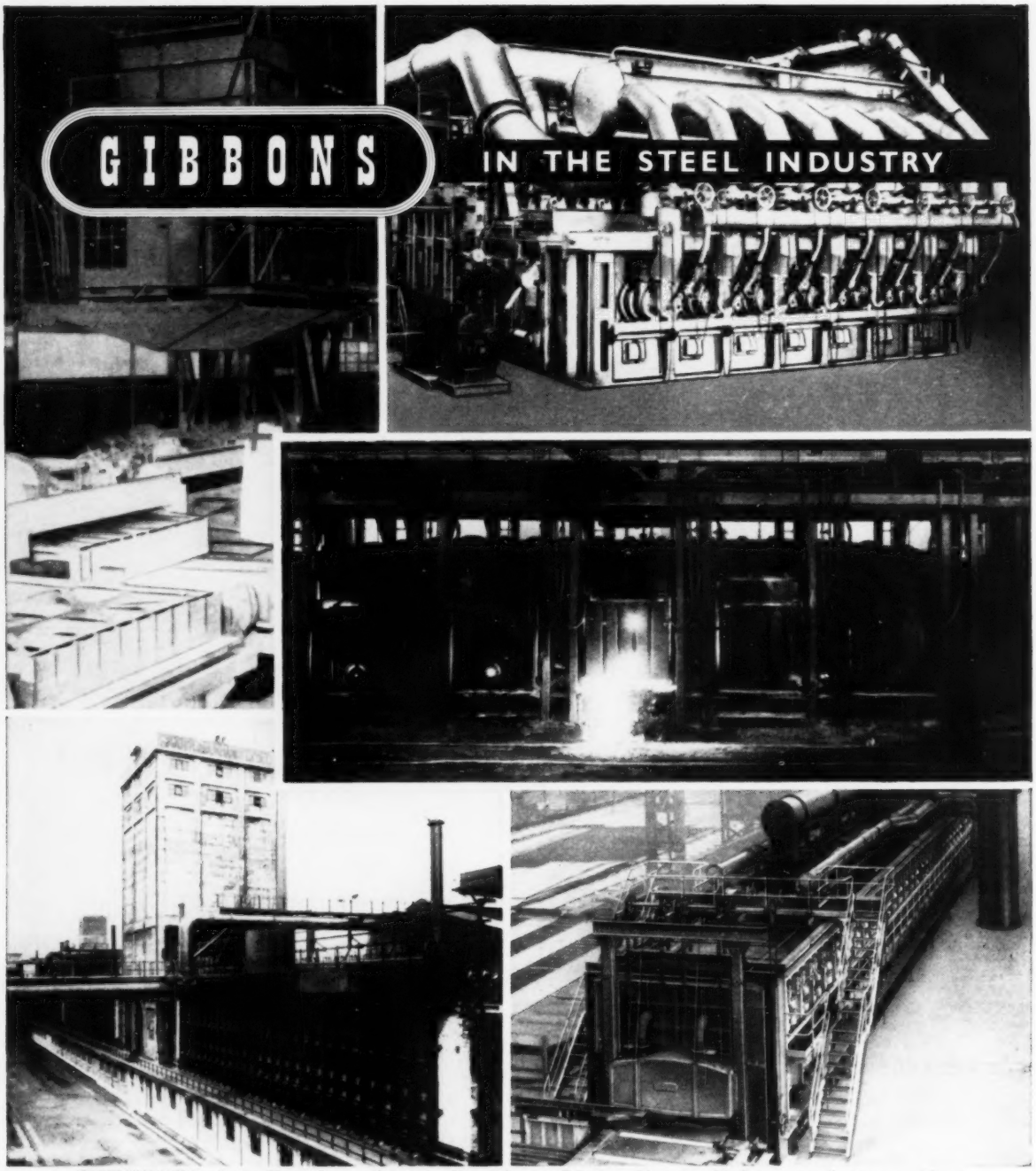

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JETTY TRACKS BY SUMMERSON'S

This installation for the Tunnel Portland Cement Company, involved the manufacturing and laying of rail and crane tracks along the new jetty and joining up to existing tracks on the old jetty. The tracks are 75 lb. F.B.B.S. 'R' and 98 lb. F.B.B. Railways section.

The combination joining the new and old jetties to the main access tracks, is a treble junction and Goliath crane track comprising three turnouts, three diamond crossings and thirteen crane crossings, all prefabricated and laid down as a unit at our Works to ensure the minimum disruption to traffic. In addition, six throughroads were manufactured and installed as well as 1,053 yards of straight and curved crane and rail track, most of the crane track angle guarded.

This is yet another example of Summerson's resources and 120 years experience in the design, manufacture and laying of railway sidings.

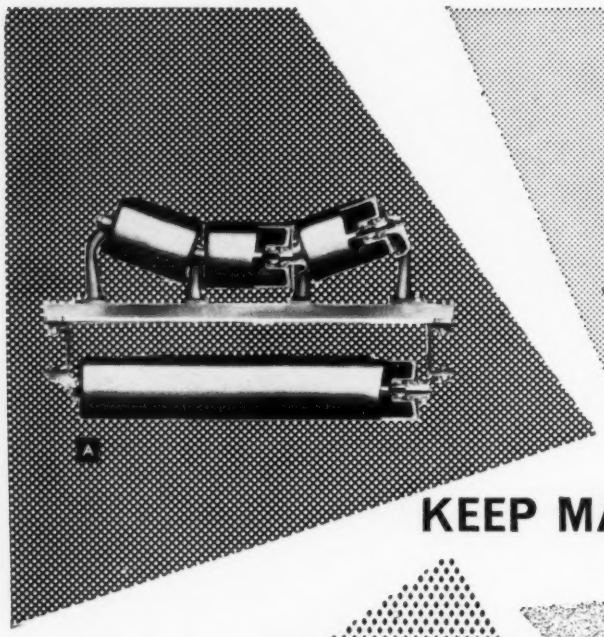
Main Contractors:
J. L. Kier & Co. Limited
Monberg & Thorsen A/S

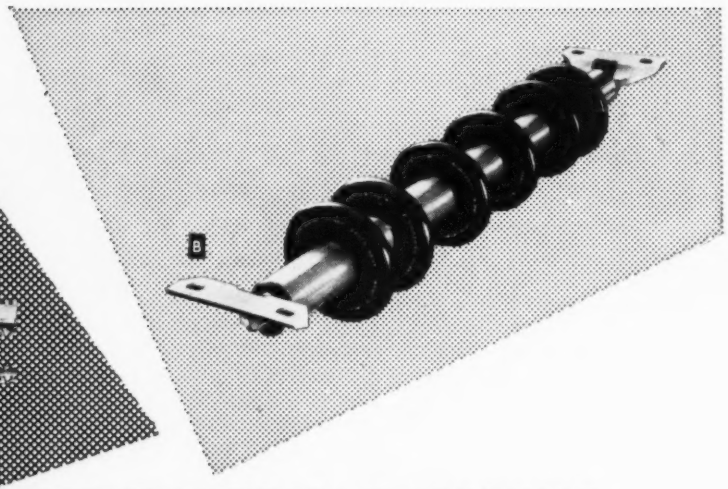
Consulting Engineers:
Sir Alexander Gibb & Partners'

Always consult Summerson first on railway siding problems

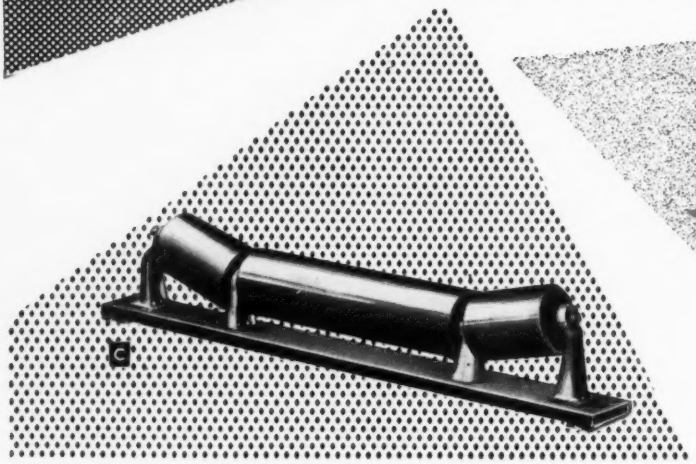
THOMAS SUMMERSON & SONS, LTD., MOWDEN HALL, DARLINGTON DARLINGTON 5226

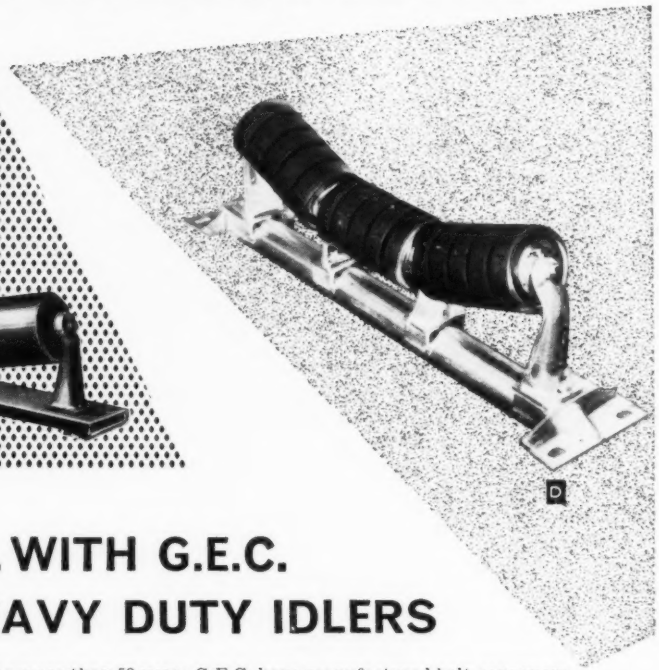
London Office: 5a Dean's Yard, Westminster, S.W.1. Abbey 1365-6-7.





KEEP MATERIALS MOVING





A *6" diameter steel tube troughing idler and return idler.* Rollers are made from mild steel tube 6" outside dia. and 6 s.w.g. Strong, rolled section steel idler base board. All troughing idlers, except on reversible belts, provided with tilting blocks to aid training of the belt.

B *7¼" diameter rubber disc return idler.* Tube carrying discs is solid drawn 6 s.w.g. and 3" outside dia. Discs are strengthened internally with mild steel ring and remain rigidly in position. Idler especially suitable where damp and sticky materials are handled.

C *6" diameter steel tube feeder idler.* Rollers are mild steel tube 6 s.w.g., and 6" outside dia. Contour of idler is designed so that material can be drawn freely from hoppers, etc., in relatively large quantities at low speeds.

D *6" diameter rubber disc impact idler.* Tube supporting discs is solid drawn ¼" thickness and 21" outside dia. Idler base board is constructed for exceptionally arduous duties. Discs are designed to support and protect belt at loading points, cushioning shock when impact is severe.

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For more than 50 years G.E.C. have manufactured belt conveyors. Shown above is a variety of heavy duty idlers which have been developed through extensive research and 50 years' experience in the materials handling field. Important features of these idlers are—

SEALS designed to retain lubrication and exclude dust and abrasive matter—thus reducing friction and wear.
BEARINGS of a taper roller type capable of a continuous load of 1,500 lb., giving a high factor of safety.
SINGLE SHOT LUBRICATION on either outside bracket. All bearings need only infrequent lubrication.
BRACKETS cast from malleable iron, designed for maximum strength and resistance to shock loads and breakage.

All components are proportioned to allow for corrosion, abrasion and normal abuse.
Special equipment can be supplied to meet abnormal conditions.

For further information write for Publication No. 2829

G.E.C.

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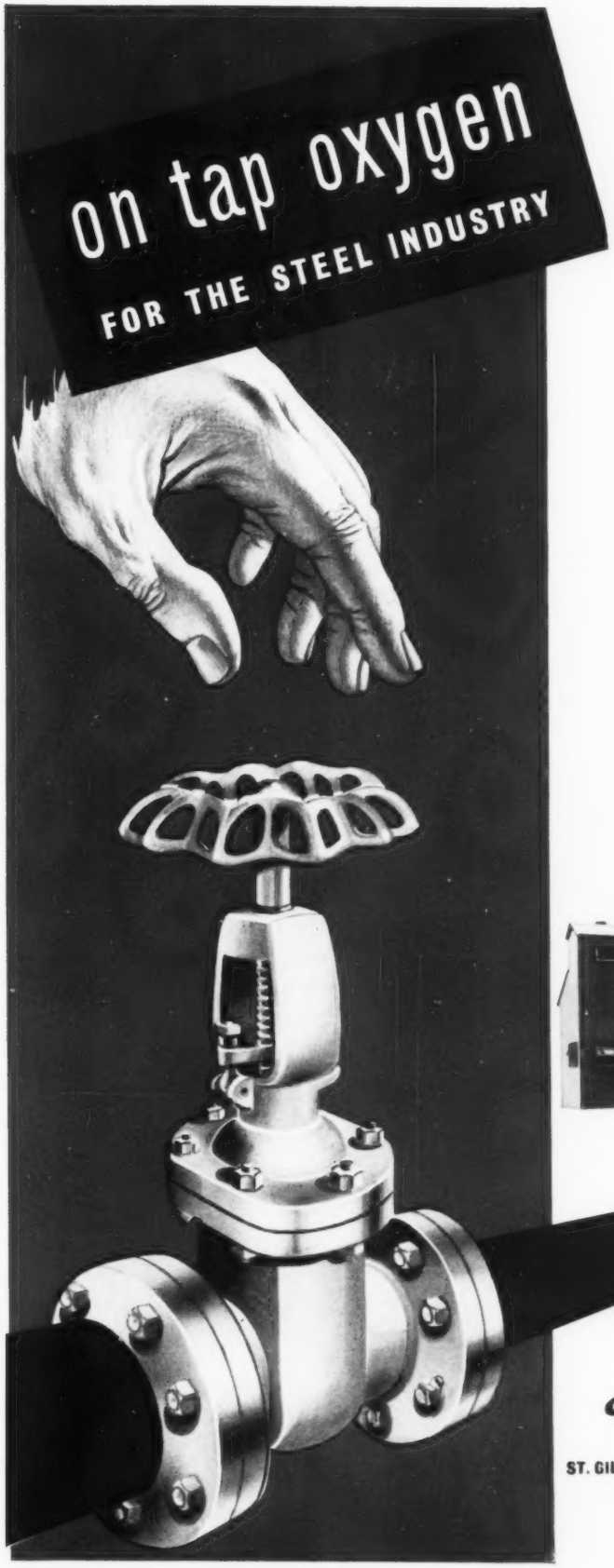

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An Air Products On Site Tonnage Oxygen supply system ensures continuity and reliability of supply at consistent high purity at minimum cost.

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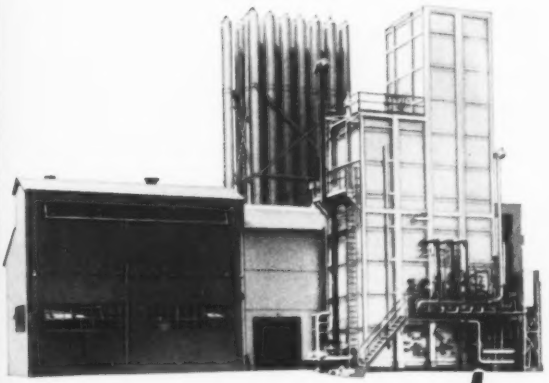

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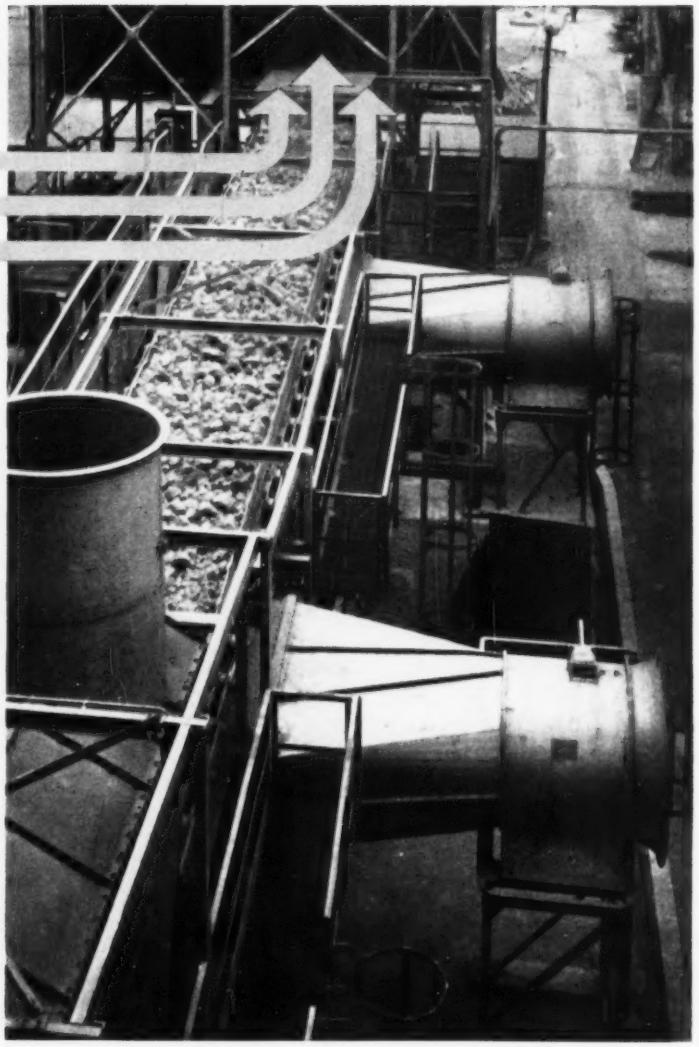
SPEEDING THE SINTER FLOW

This photograph was taken looking down on the sinter cooler at Barrow Ironworks. On the right of the cooler can be seen two of the three fans which have reduced the cooling interval so efficiently

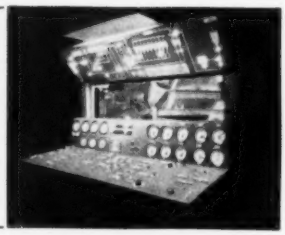


For 70 years, we have made steady improvement in the sintering process our business, and each sinter plant we design and install incorporates the latest developments in sintering technique.

At many new sinter plants, including those at Barrow Ironworks, Consett Ironworks, the Iron and Steel Corporation of South Africa, Cockerill-Ougrée (Belgium) and the Société Métallurgique de Normandie (France), a new Huntington Heberlein cooler has increased the efficiency of the sinter process. High quality sinter is being cooled in 20 minutes from 600 C for transmission on normal belt conveyors. This cooling is achieved by forced circulation from cold air fans which work at very low power consumptions.

Associated in the U.S.A. with Koppers Company Incorporated, our other specialities include: Ore Dressing Plants, High Intensity Magnetic Separators, Herreshoff Furnaces and Badische Turbulent Layer Roasters.

The feed rate control panel at Barrow



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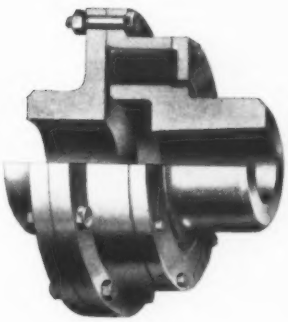
HOLSET FLEXIBLE Rubber Block COUPLINGS

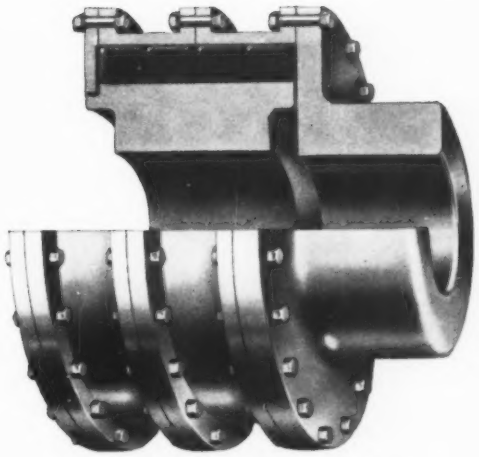
for ROLLING MILL MAIN DRIVES and all AUXILIARIES

CHARACTERISTICS OF HOLSET COUPLINGS

- Can accommodate substantial angular and parallel misalignment.
- Absorb shocks and operate noiselessly under any conditions.
- With a multi-row arrangement of the blocks, Holset Flexible Couplings can have a small diameter and, therefore, a lower WR^2 value than any other torsionally resilient coupling.
- Do not create any end thrust on the bearings of the connected shafts.
- Provide electrical insulation between the driving and driven machines as there is no metal to metal contact.
- Do not require lubrication or maintenance of any kind.
- Installation of Holset Flexible Couplings is simplicity itself. As there are no spigots, removal of the bolts permits vertical lift of the driving and driven machines.
- The design is consistent throughout the range of standard sizes which extends to couplings with a torque capacity of 400 metre tons.

Mill Motor Coupling up to 200 h.p.





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SAVE TIME with Rawlbolts. Grouted ragbolts will take 3 days to harden before the machine can be used. Use Rawlbolts and the machine can be in production in much less than 3 hours. It can be moved easily to a new position when necessary.

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Write now *for descriptive broadsheet of R 1480 which incorporates a half size Rawlbolt Reference Chart.*

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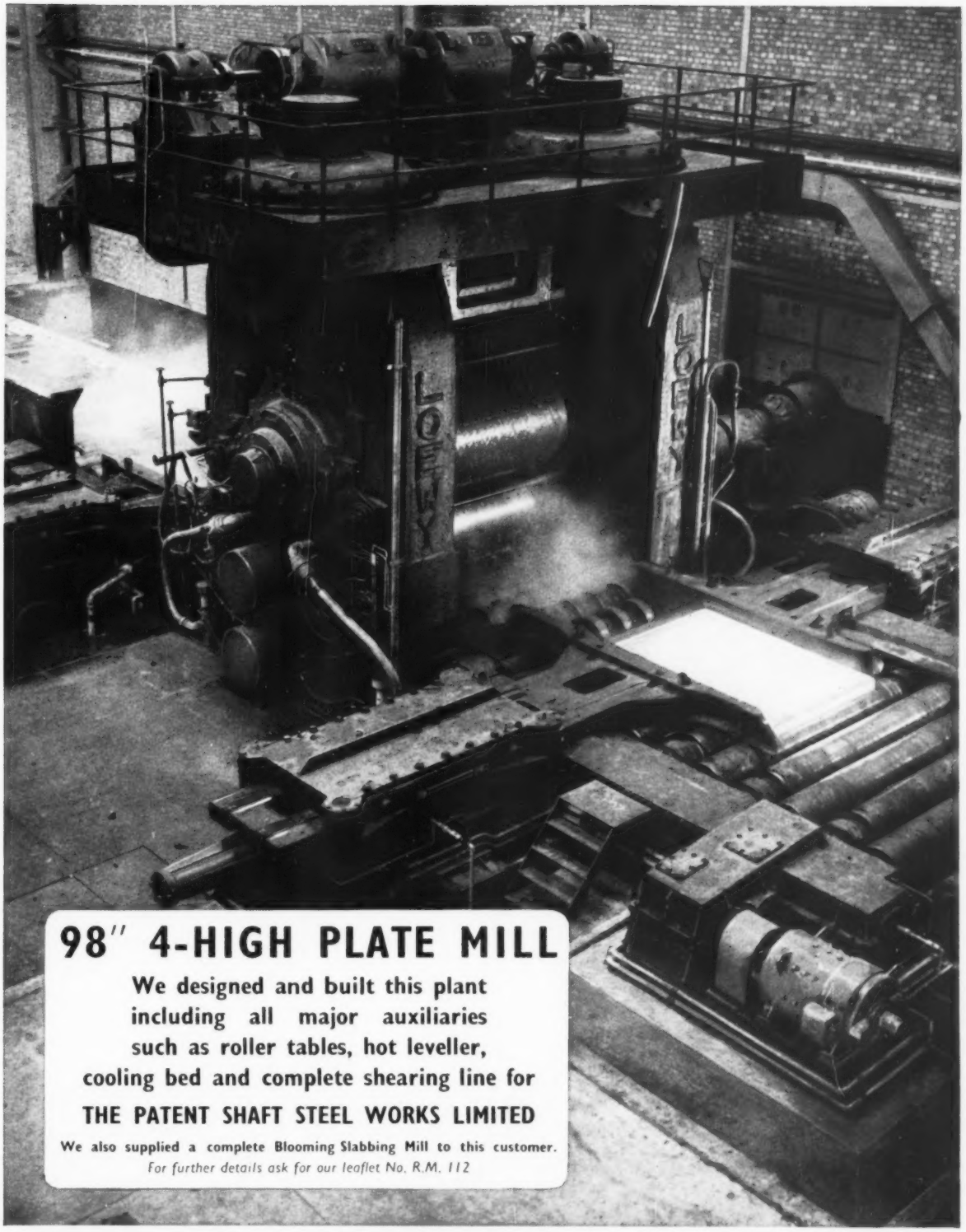


98″ 4-HIGH PLATE MILL

We designed and built this plant including all major auxiliaries such as roller tables, hot leveller, cooling bed and complete shearing line for

THE PATENT SHAFT STEEL WORKS LIMITED

We also supplied a complete Blooming Slabbing Mill to this customer.

For further details ask for our leaflet No. R.M. 112

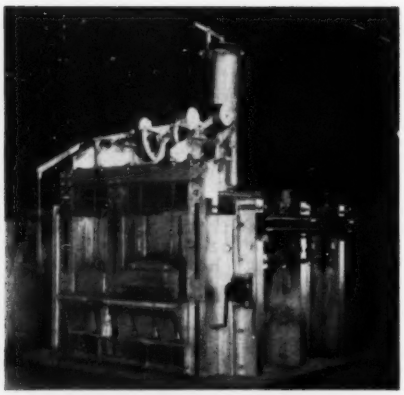
THE LOEWY REGD. TRADE MARK **ENGINEERING COMPANY LTD.**
BOURNEMOUTH ENGLAND

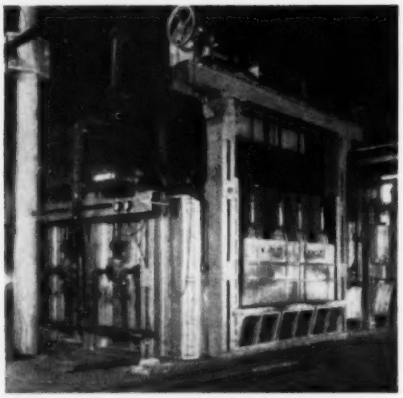
Modern Forge Furnaces

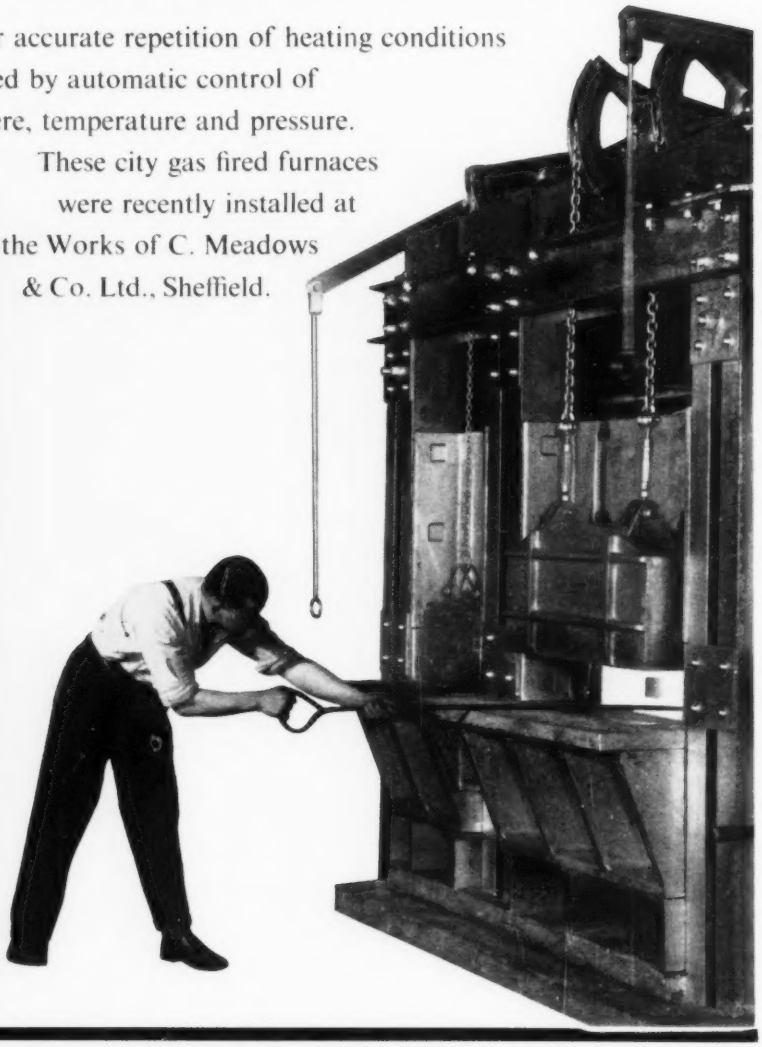
FIRED BY FUEL OIL, PRODUCER GAS OR CITY GAS

The increased demands for accurate repetition of heating conditions is ensured by automatic control of furnace atmosphere, temperature and pressure.

These city gas fired furnaces were recently installed at the Works of C. Meadows & Co. Ltd., Sheffield.







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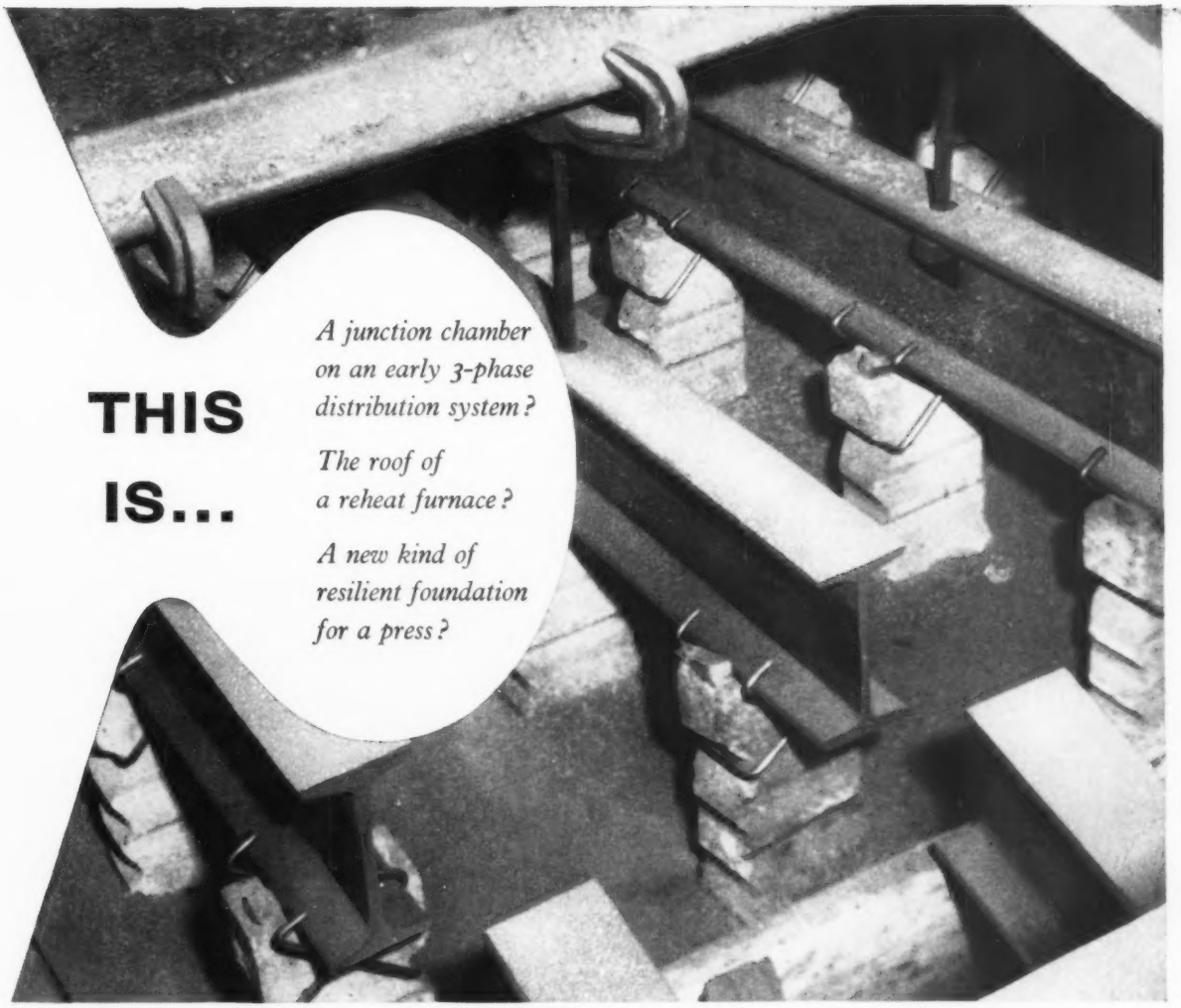
G.P. WINCOTT LIMITED SHEFFIELD, ENGLAND

Telegrams: WINCOTT, SHEFFIELD. Telephone: 20211/2


THIS IS...
A junction chamber on an early 3-phase distribution system?
The roof of a reheat furnace?
A new kind of resilient foundation for a press?

Number two is the right answer. It is part of the monolithic roof of a reheat furnace at the Margam works of the Steel Company of Wales, immediately before the refractory was placed.

The special anchor bricks hanging from the R.S.J's are secured by heat-resisting clips and will provide support through the full thickness of the refractory lining.

This roof was cast in "TRI-MOR" High Temperature Castable. It is a good example of the type of furnace lining which "TRI-MOR" refractories and Morgan's whole-hearted belief in monolithic structures have made possible.

Some of the most useful of the "TRI-MOR" refractories are:—

TRI-MOR Standard Castable
TRI-MOR High Strength Castable
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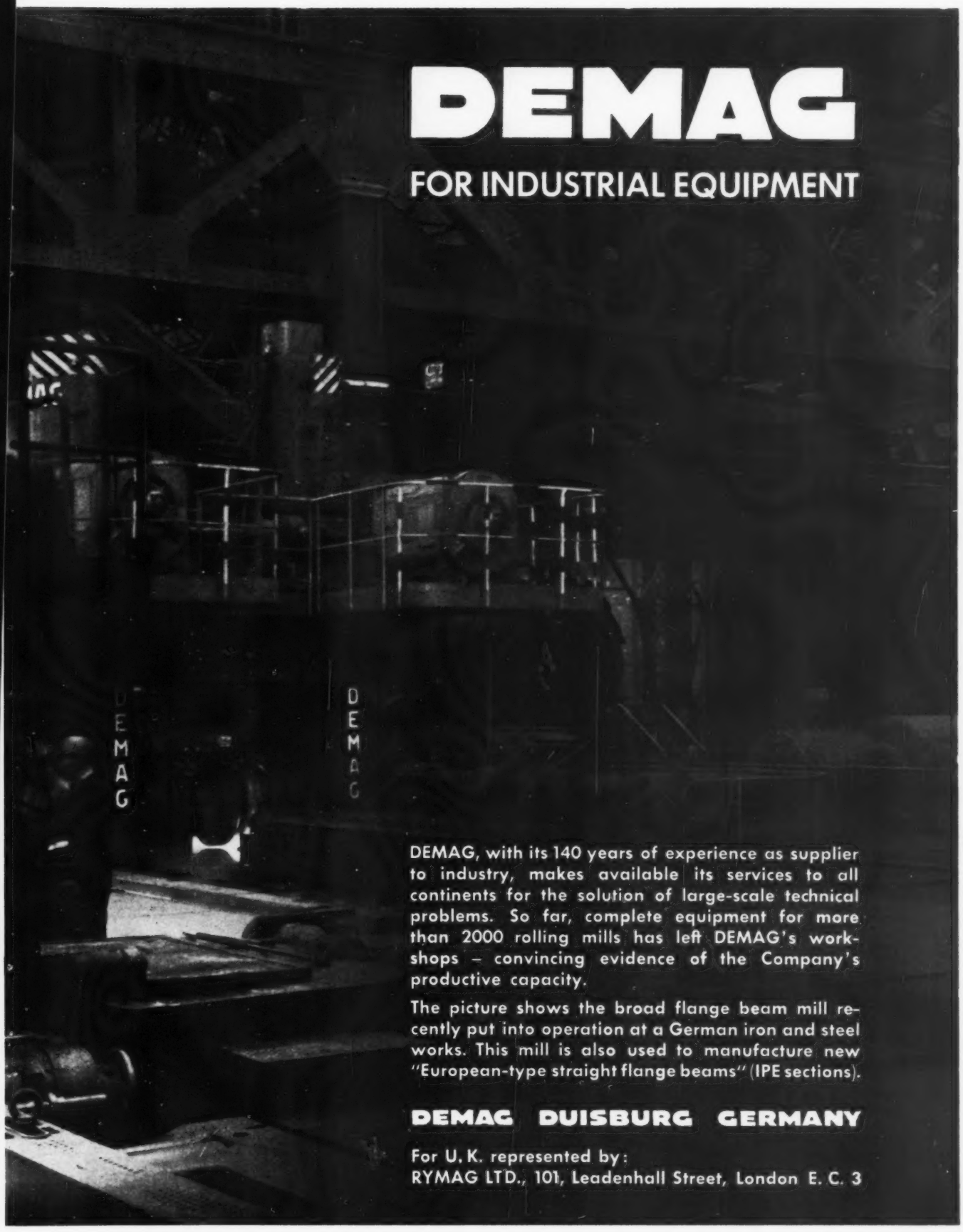
FOR INDUSTRIAL EQUIPMENT



DEMAG, with its 140 years of experience as supplier to industry, makes available its services to all continents for the solution of large-scale technical problems. So far, complete equipment for more than 2000 rolling mills has left DEMAG's workshops – convincing evidence of the Company's productive capacity.

The picture shows the broad flange beam mill recently put into operation at a German iron and steel works. This mill is also used to manufacture new "European-type straight flange beams" (IPE sections).

DEMAG DUISBURG GERMANY

For U. K. represented by:
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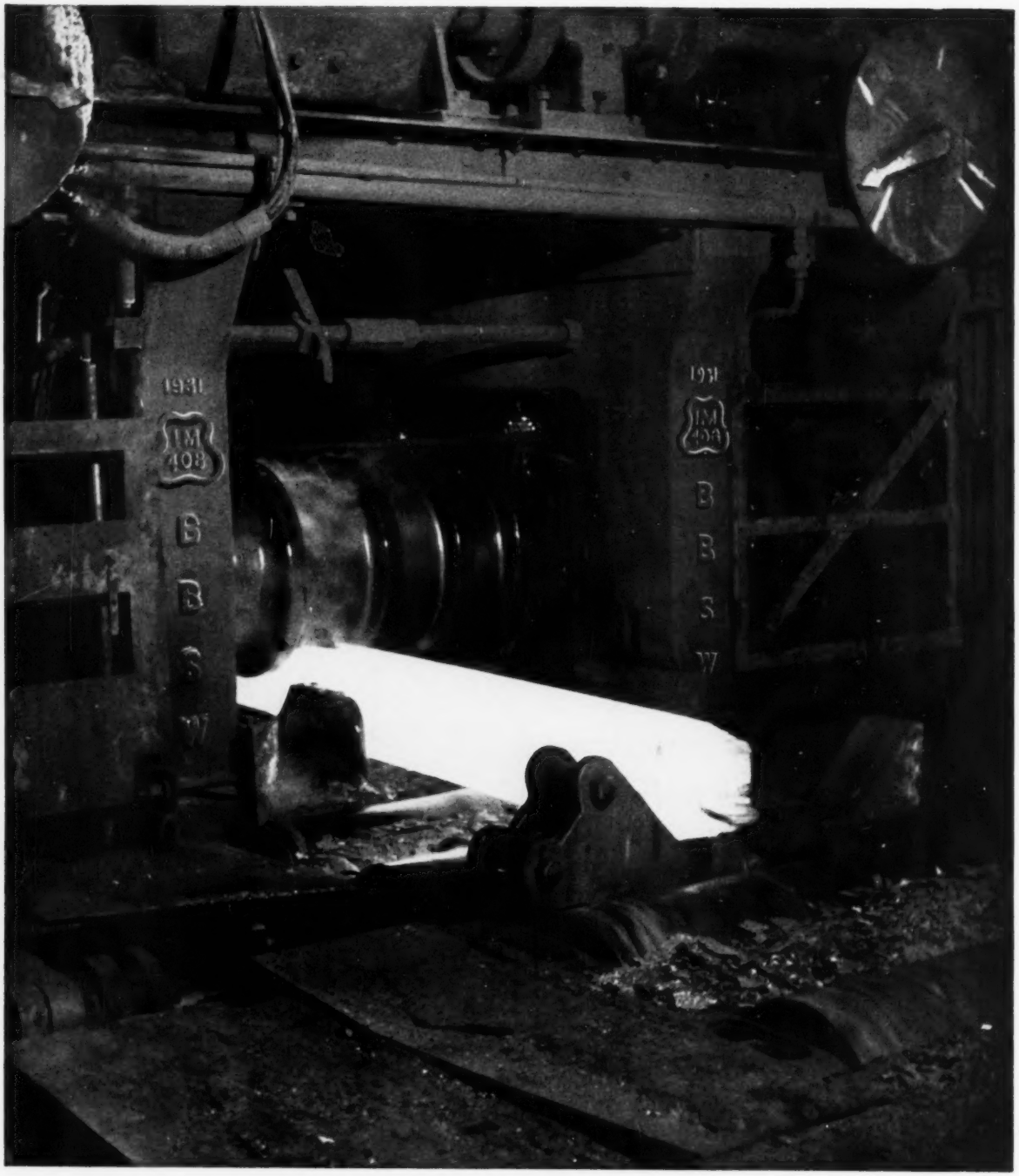

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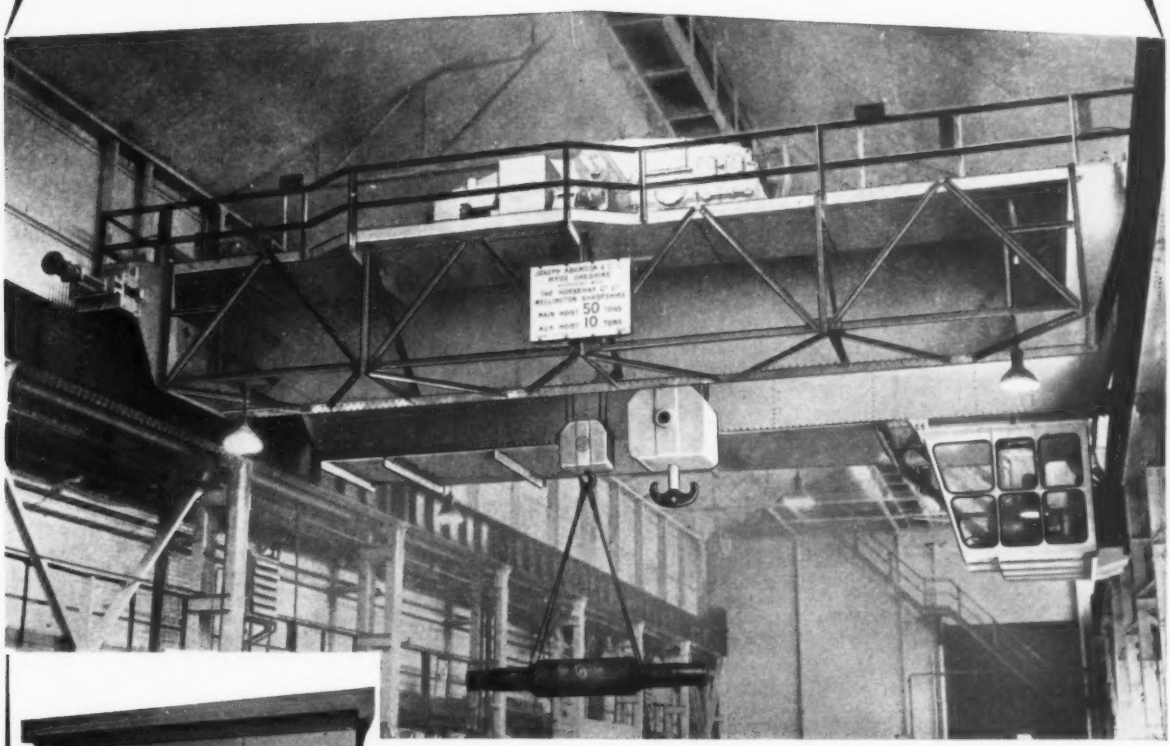
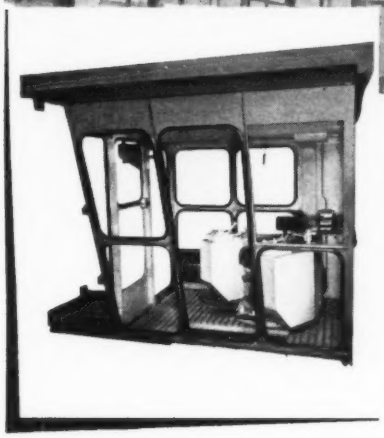
ELECTRIC OVERHEAD TRAVELLING CRANES





★ *a view of the cab showing the seat control unit.*

The Adamson 50/10 ton crane is the third of a series of new design supplied to Richard Thomas & Baldwins Limited, Ebbw Vale Section. Features of the crane include monolithic construction of the crab and the elimination of castings by mild steel fabrication of the hoist barrel and bottom block. The cab is of particular interest as it incorporates the most modern type of seat unit ensuring maximum vision and ease of control. Joseph Adamson electric overhead travelling cranes can be supplied to all specifications including cranes suited to the most exacting 24 hours-a-day process work.

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JOSEPH ADAMSON & CO. LTD.

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THE ADAMSON GROUP

Fuel Selection for Annealing Castings

"replacing an existing furnace by one using town gas due to the high maintenance and replacement costs incurred with existing equipment"

Langley Alloys Ltd., manufacturers of the well-known "Langalloy" and "Hidurax" alloys, face a problem common to most heat treatment process users in that they need a flexible plant to treat loads varying in size and metallic composition.

For example, a recently installed furnace at Langley Alloys Ltd. is used primarily for the heat treatment of corrosion resistant castings in the "Langalloy" series of nickel-based and stainless steel alloys, yet it had to be satisfactory for hardening and tempering large forgings in aluminium, bronze and other copper-based alloys.

The nickel-based alloy castings include nickel-molybdenum-iron and nickel-chrome-molybdenum alloys which are solution heat treated by holding them at temperatures ranging from 1,150°C to 1,250°C followed by a water quench or air blast. This treatment ensures maximum corrosion resistance and eases the machineability.

Stainless steel castings include chromium steels and various grades of chromium-nickel austenitic steels, and the heat treatment is carried out at 950°C to 1,100°C, after which they are water quenched.

THE PROBLEM

The North Thames Gas Board Industrial Department was asked to collaborate in replacing an existing furnace by one using town gas due to the high maintenance and replacement costs incurred with the existing equipment. It was pointed out that the furnace hearth was subjected to hard wear caused by heavy parts being dropped on to it during loading. A bogie hearth furnace was suggested measuring 4 ft. 0 in. long by 3 ft. 0 in. wide. After the bogie hearth was withdrawn it had to be capable of being tilted so that the articles could be tipped into a side quenching tank. A maximum temperature of 1,250°C held within ±10°C was also stipulated.

A further requirement was a steel table used as a loading platform at the same height as the bogie hearth with a quenching tank sunk into the floor.

THE EQUIPMENT

The North Thames Gas Board discussed the requirement with the furnace manufacturers, and eventually a furnace was supplied and fitted to the following specification:

Dimensions of Furnace—Door opening 3 ft. 6 in. wide and 1 ft. 11 in. high from the top of the bogie to the spring of the door arch. Length from door face to back wall of 4 ft. 10½ in.

Wall and Arch Construction—Lightweight insulating refractory backed with diatomaceous insulation.

Casing—Totally enclosing the brickwork except the roof. Adequate in strength to prevent any distortion. Finished in heat resisting aluminium paint.

Bogie Construction—High quality firebrick top backed with insulating refractory. Door forming back of the bogie lined with lightweight insulating refractory and diatomaceous material. Sandseals on the sides and end of the car to prevent hot gases

Fig. 1

A front view of the gas-heated annealing furnace at Langley Alloys Ltd. showing the furnace construction and the hearth part withdrawn towards a sunken quench tank.

escaping from the furnace chamber. Wheel axles in roller bearings for easy bogie movement. Hand wheel operated clamping screws on door to lock the bogie in position—the door protecting the operator against radiation as the bogie is withdrawn. Manual withdrawal by a chain and bevel gear drive to the wheels with operating handle at a convenient height on the back of the door. Sufficient rail length for withdrawal of the bogie clear of the mouth of the furnace for loading and unloading.

Gas Burner Equipment—Two air blast burner blocks firing from the rear wall on each side of the furnace. No flame impingement on the charge—the hot gases, after passing to the door, are drawn back through flues in the rear wall arranged at bogie hearth level. Flues connected to a common outlet with damper control. Each burner set provided with graduated air and gas control cocks. A motorized valve, wired through a temperature control panel, simultaneously operates valves in the main air and gas supplies according to the heat input requirements.
Other controls on the main gas supply include a constant pressure governor, non-return valve and a solenoid operated main shut-off valve.

Air Supply—Fan blower at 22 in. w.g.

Loading Equipment—Mild steel loading table is provided with a top for easy loading of the work on to the bogie. As the hearth is at temperature all loading is carried out with tongs.

Unloading—A hand operated tilting device, the door again shielding the operator from the high temperature during bogie tilting. Locking device provided holding the bogie to the rails during this operation.

Quench Tank—Mild steel plates, suitably braced. 3 ft. 0 in. wide by 4 ft. 6 in. deep by 5 ft. 0 in. long to quench 500 lb of castings with a water temperature rise to 140°F.

Safety Control—Diaphragm switches in both air and gas lines connected to solenoid valve in the main gas line. The solenoid valve closes with failure of gas or air supply and cannot be opened until it has been manually reset.

Test Results—Tests were made during a day's operation to determine the performance of the furnace under normal operating conditions. The working temperature of 1,050°C was obtained in 1¾ hours after lighting from cold for a gas consumption of approximately 12½ therms. The time to recover working temperature following loading was between a quarter and half an hour, depending upon the size of the charge.
One charge consisted of 291 lb of small castings of nickel based stainless steel, and the working temperature was recovered in 20 minutes for a consumption of 2½ therms of gas. A further 4 therms were consumed whilst one hour's soaking was taking place, giving a total of 6½ therms for the treatment of the charge.
It is estimated that to heat the furnace and a 500 lb. charge to 1,250°C would take 3 hours and require approximately 25½ therms of gas. For a follow-on charge of 500 lb, assuming the furnace to be at 1,350°C and the bogie at 1,000°C, would take 1 hour with a gas consumption of 11½ therms.

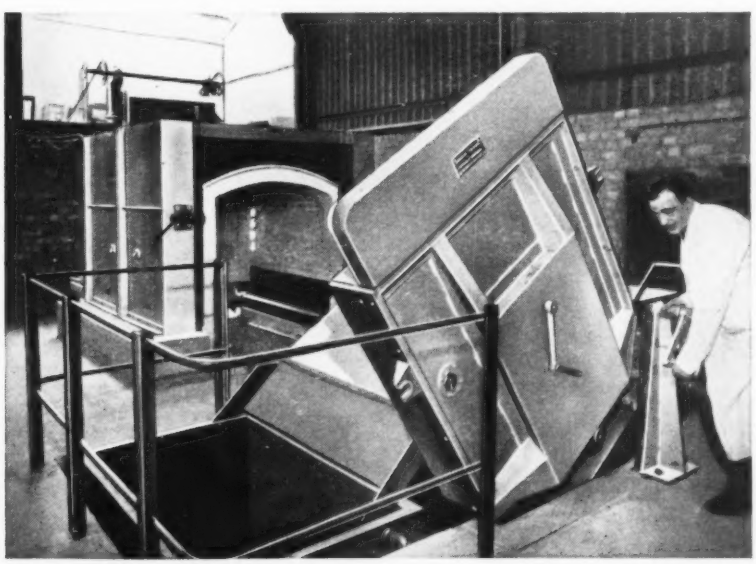

Fig. 3
A view showing the hearth completely withdrawn—the door protecting the operator from radiation from the charge—and being tilted towards the quenching tank.

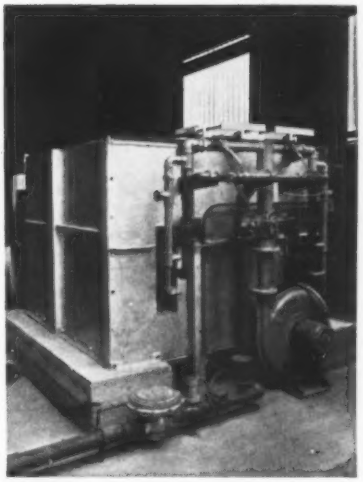

Fig. 2
A rear view of the annealing furnace showing the gas/air controls and safety devices.

. . .

Langley Alloys Limited also use town gas in their foundry for shell moulding, core drying, ladle drying and other specialised foundry requirements as well as for canteen and welfare purposes.
This is one example of collaboration between the user and plant supplier where the North Thames Gas Board offered a free consulting service. An Industrial Gas Officer at any Area Gas Board can avail himself of the experience of his colleagues in other Gas Boards through the medium of the Gas Council's Industrial Gas Development Committee. And, of course, heat treatment is but one of the many trades, professions and occupations using the facilities and research of the British Gas Industry.

Scottish Gas Board, Edinburgh
Northern Gas Board, Newcastle-upon-Tyne
North Western Gas Board, Manchester
North Eastern Gas Board, Leeds
East Midlands Gas Board, Leicester
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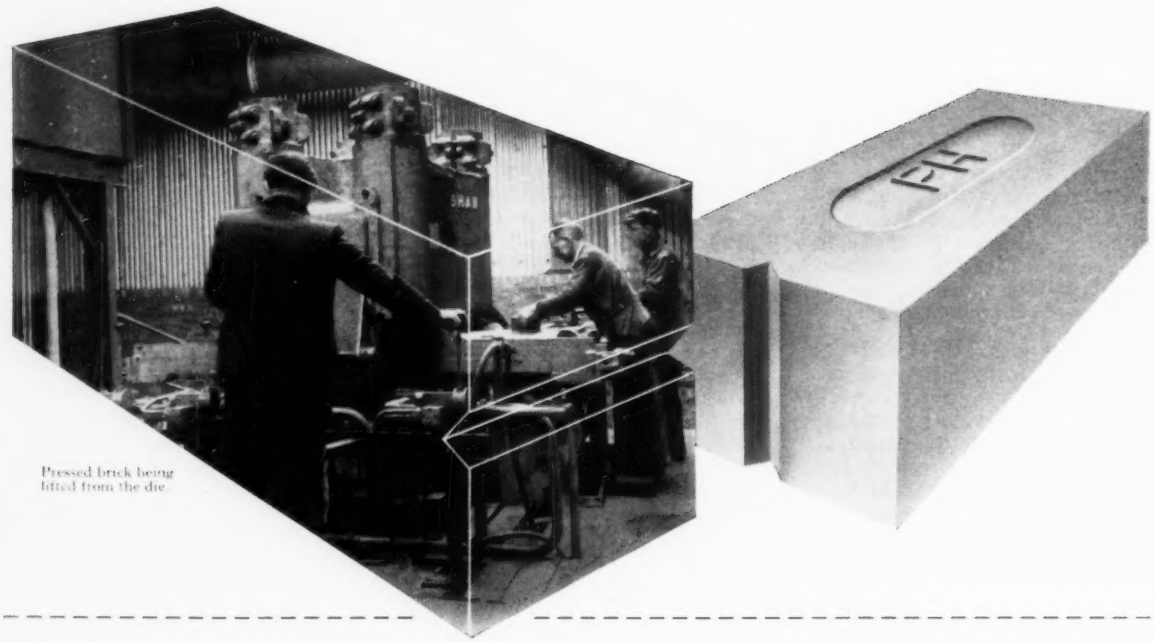
South Eastern Gas Board, Croydon
Southern Gas Board, Southampton
South Western Gas Board, Bath

The Gas Council, 1 Grosvenor Place, London, S.W.1



Pressed brick being lifted from the die

PRESSING PROBLEM SOLVED

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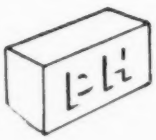

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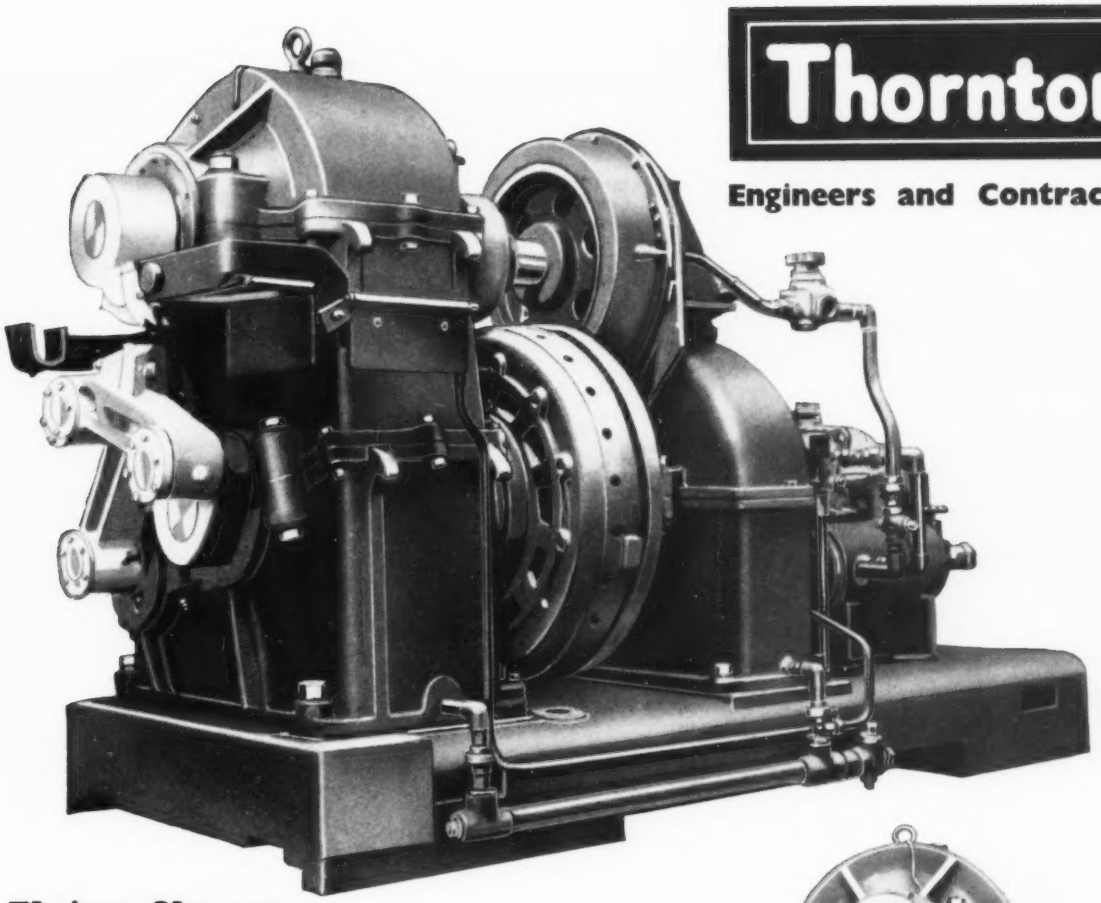

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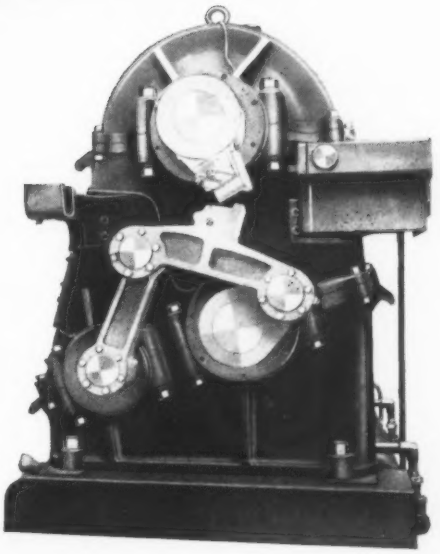

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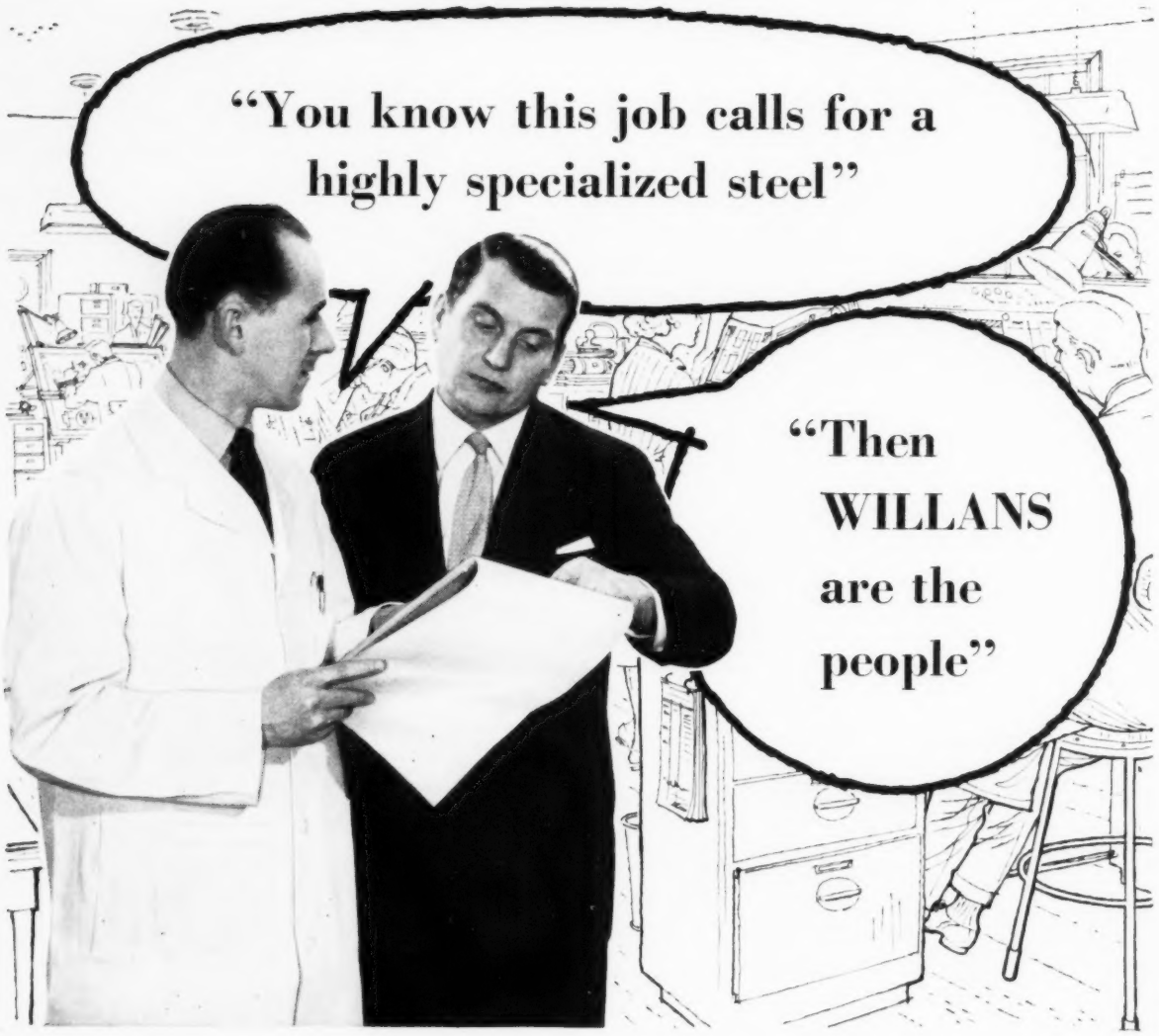

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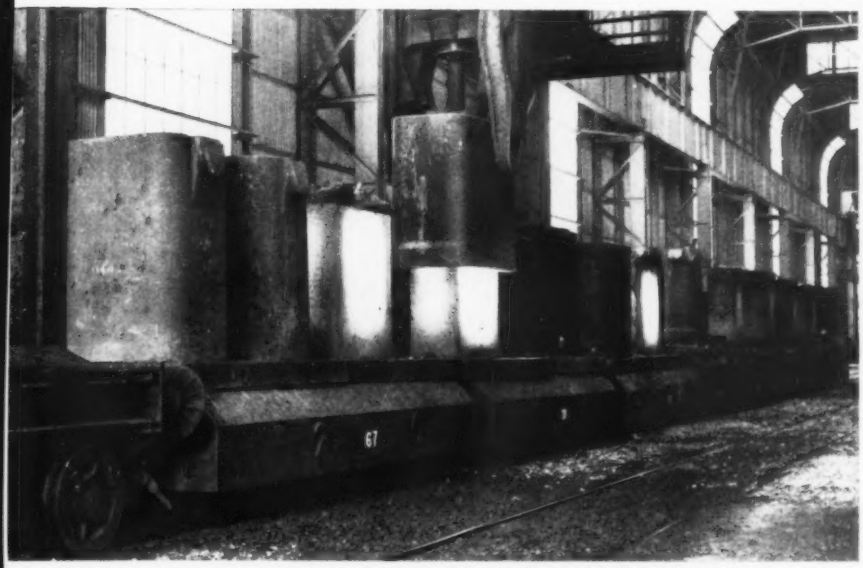

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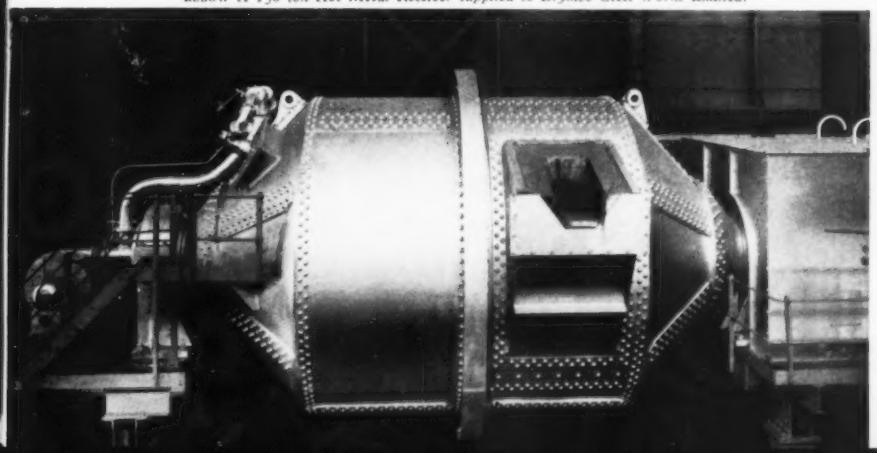

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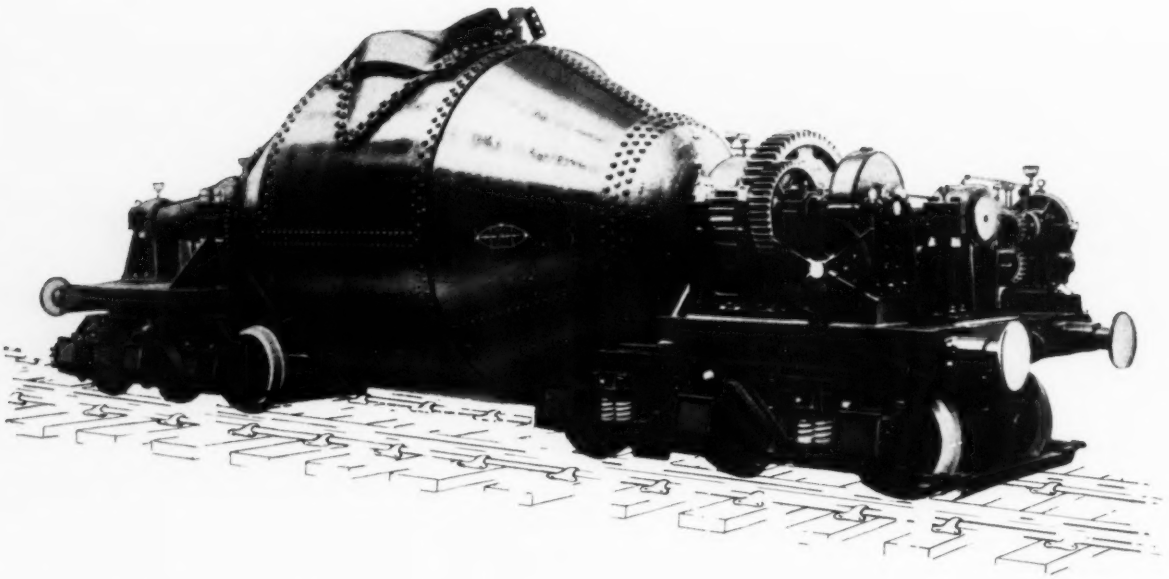

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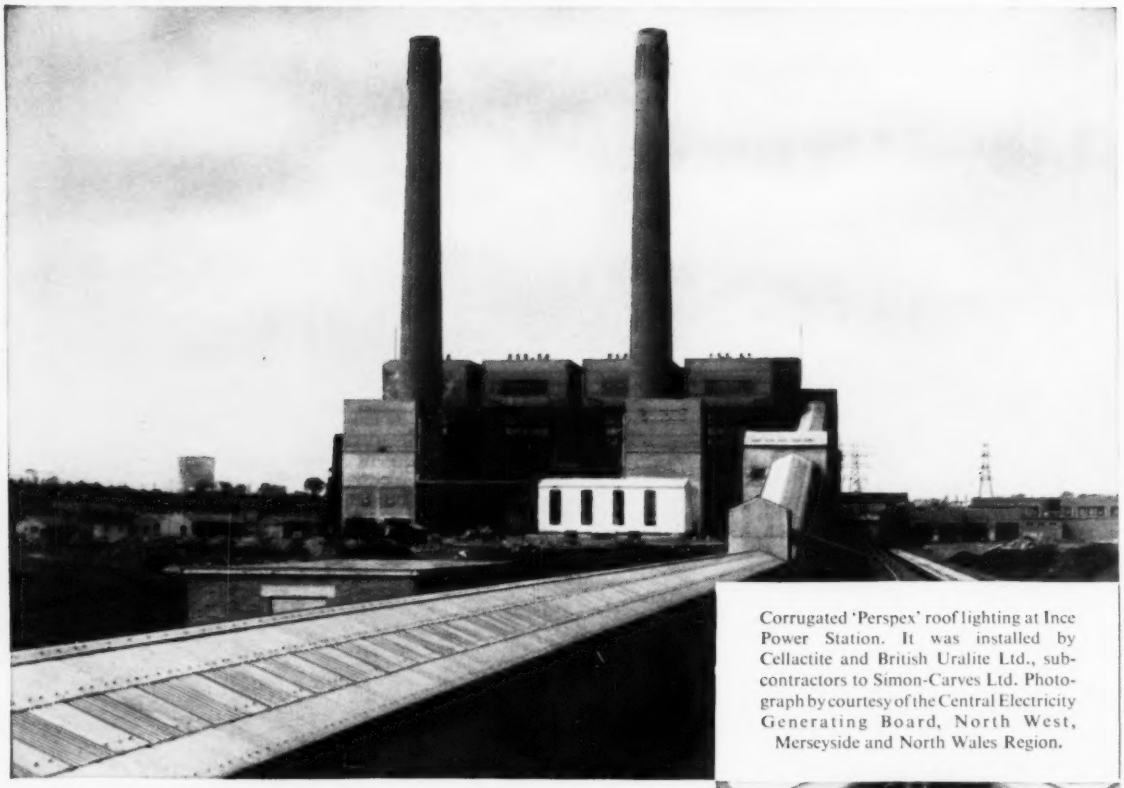

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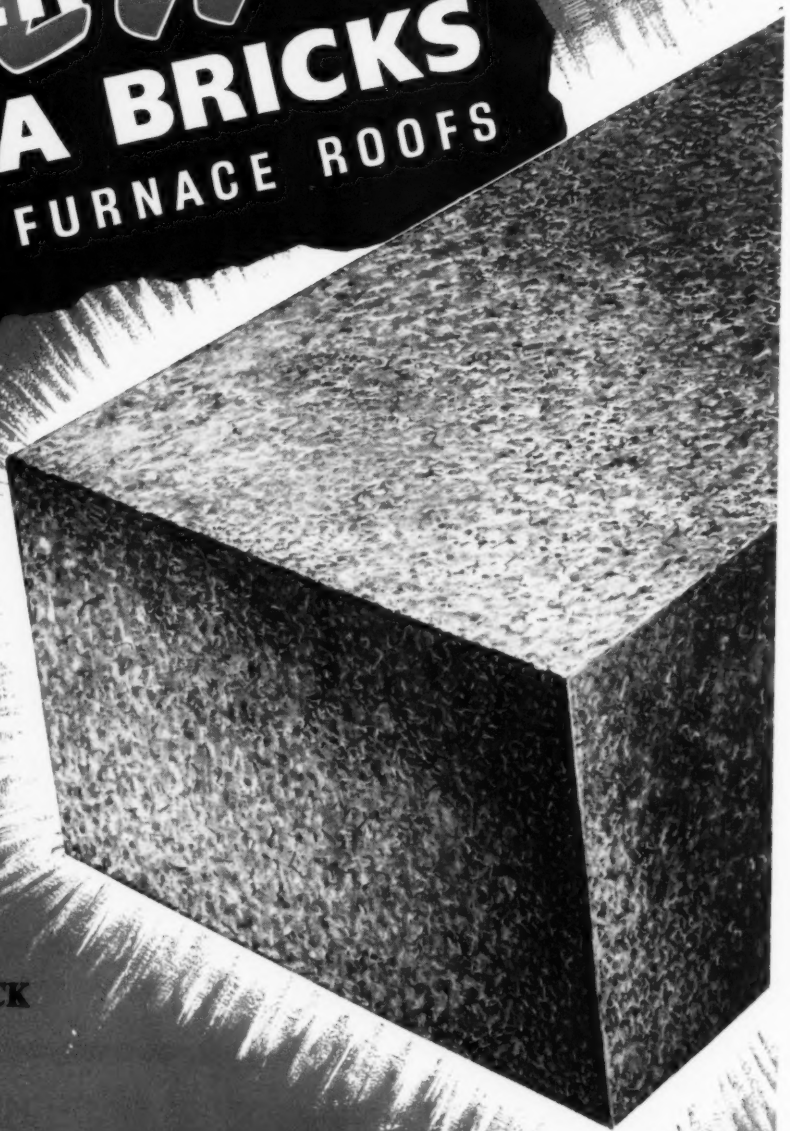

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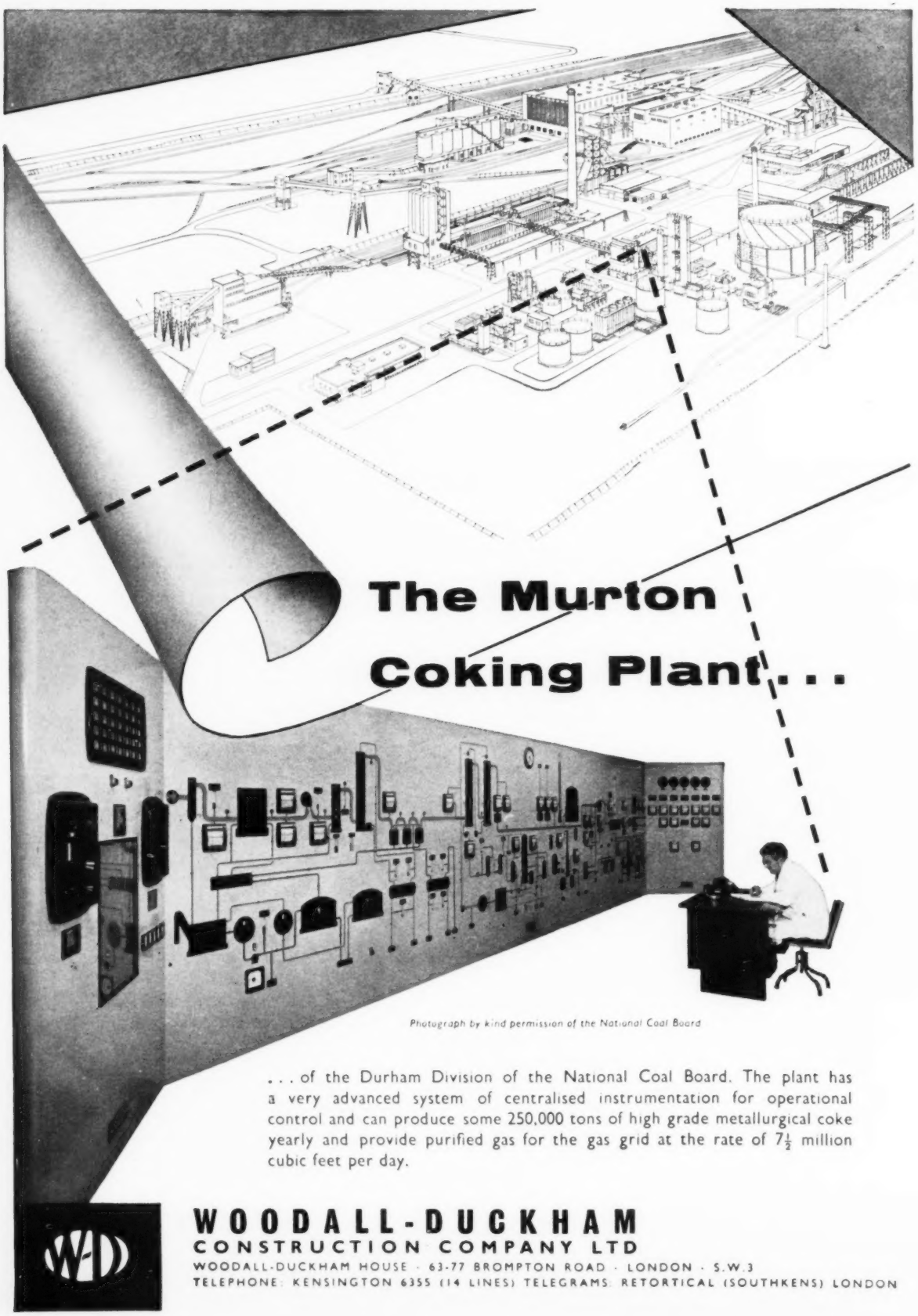

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Journal of The Iron and Steel Institute

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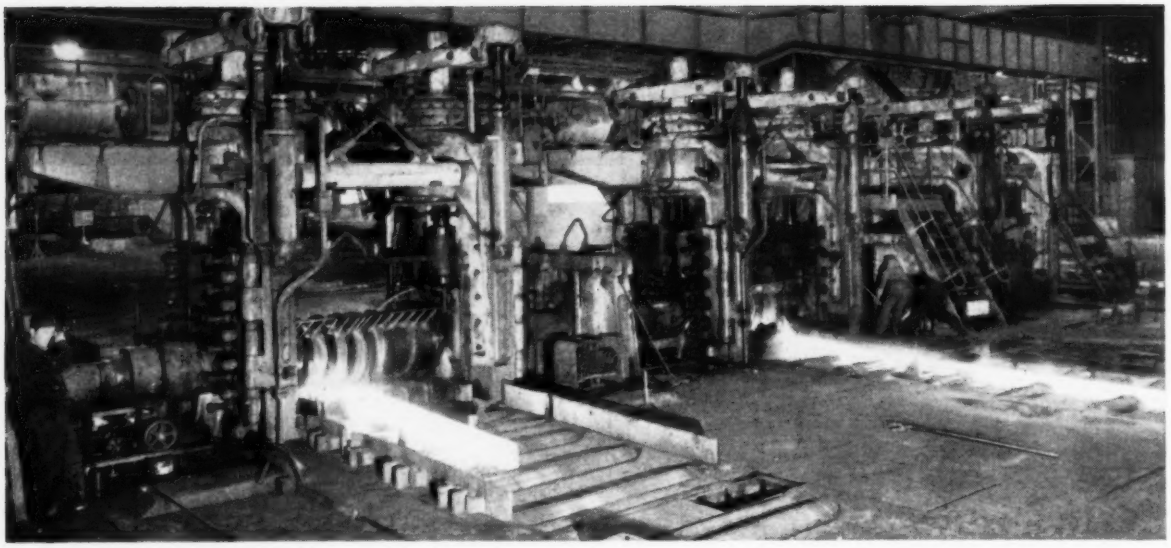

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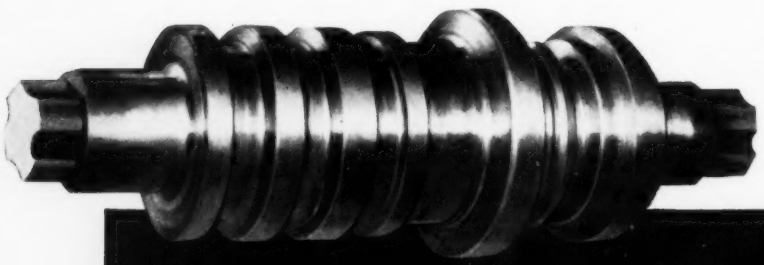

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W. H. B. WESSON, T.D.

WILLIAM H. B. WESSON was born in 1912, third generation of a family of iron masters. He was educated at Ellesmere School before joining the family firm of W. Wesson and Co. in 1929 and becoming apprenticed to the United Steel Companies. In 1932 he was appointed mill manager of W. Wesson and Co.

In 1937 Mr Wesson was commissioned in the West Bromwich Battery of Royal Artillery (Territorial) and was mobilized in 1939, when he fought with the B.E.F. He has since received the Territorial Decoration for his service.

He returned to W. Wesson and Co. in 1942 and became a director of the company two years later. In 1946 he reported to the Ministry of Supply on the German re-rolling industry.

Mr Wesson has been a director of The Moxley Rope Works Co. Ltd since 1956. He resigned from the board of W. Wesson and Co. in 1958. Elected to the Council of the Staffordshire Iron and Steel Institute in 1953, Mr Wesson became its president for the year 1958–59, during which period he served as an Honorary Member of the Council of The Iron and Steel Institute.

W. H. B. Wesson, T.D.
Honorary Member of Council, 1958–59

Factors affecting fuming in open-hearth furnaces

C. Holden

SYNOPSIS

Techniques of sampling fume from the waste-gas duct or chimney have now been developed to a standard which is adequate for routine measurements. Other techniques have to be used for sampling in the downtake or in the furnace chamber and although they give results which are not correct absolutely, they are, nevertheless, extremely useful for making comparisons. The results obtained so far show that more fume is produced with pitch creosote as the fuel than with oil. The quantity of the atomizing agent is important, while the type of atomizing agent also appears to have some influence. Bath injection of oxygen or air results in a large increase in the fuming rate and there also appears to be a substantial difference between the quantities of fume evolved in hot- and cold-metal practice. The amount of carbon present in the bath appears to have a strong influence on the rate of fuming and a theory is proposed based on the solution of oxygen on the surface layers. 1631

INTRODUCTION

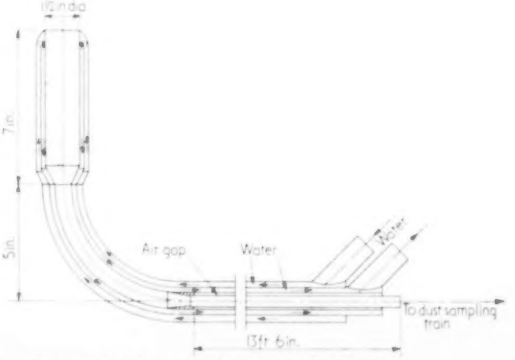
FUME FORMATION in open-hearth furnaces is vitally important for a number of reasons, e.g. its effect on blocking of checkers and flues, refractory attack, ingot yield, and air pollution. First work in this field at United Steels was done in 1949 when a number of producer-gas furnaces were converted to pitch-creosote firing, and fume formation in the checkers and flues was so excessive that furnaces had to be taken off for cleaning after only six weeks. More recent suggestions on the cause of refractory wear[1,2] indicate an almost linear relationship between wear and iron oxide deposition rate, both on silica and all-basic furnace roofs. In view of the great benefits to the steel industry of a reduction in fume formation, and in addition, the increasing importance attached to reducing air pollution, it has been thought worthwhile to present information collected over a number of years, even though it is realized that much of this is of an *ad hoc* character. If this paper leads to similar experiments of a more controlled type it will have fully justified the effort involved.

TECHNIQUES USED FOR THE MEASUREMENT OF FUME CONCENTRATION

The methods for measuring fume concentration fall into three distinct groups: optical density methods, impact probes, and extraction of gases from the system via a nozzle. For precise work the latter method is used, the gases being sampled isokinetically, i.e. at such a rate that they experience no change of velocity when entering the nozzle. The data included in this paper were obtained by several methods and, apart from the BISRA apparatus, the methods used can only be considered as crude. The results, therefore, can only be taken as comparative since such variables as the size of the fume particles and the velocity of the gas stream strongly influence the collection efficiency.

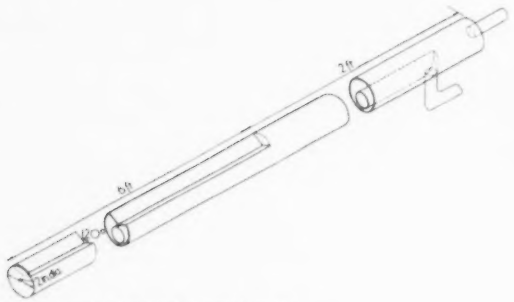
The sampling of solids from the waste-gas duct or chimney where the temperatures are low has been investigated in detail by both BCURA and BISRA.[3] With care an accuracy of the order of $\pm 10\%$ is possible, and it is doubtful whether a higher accuracy than this is required for routine purposes. Results from one furnace obtained by BISRA with their own sampling system, are quoted. The probe was made of stainless steel, not water-cooled, and the samples were aspirated isokinetically and deposited on a fibre-glass filter.

If samples are drawn from the stack the amount collected will be strongly influenced by the design and condition of the slag pocket, checkers, flue system, and

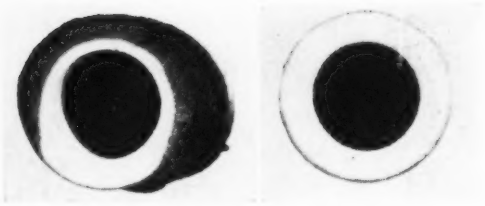


1 *Water-cooled dust-sampling probe, half full size*

Manuscript received 24 November 1958.
The author is Head of the Furnace Research Section at The United Steel Companies Research and Development Laboratories, Rotherham.



2 *Isometric sketch of* V*-notch probe*



(*a*) Outgoing end (*b*) Incoming end

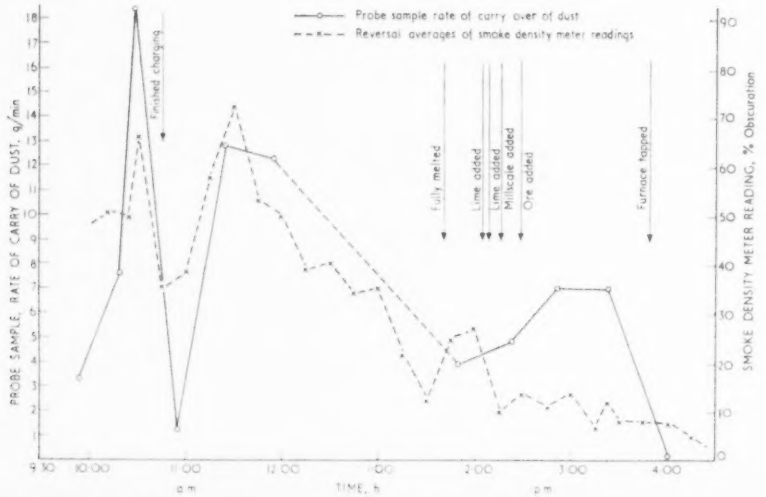
3 *Cross sections of alumina probes after use*

the presence or absence of a waste-heat boiler. Experiments have recently been carried out with a water-cooled probe which enables isokinetic sampling to be carried out even in downtakes. The probe is shown in Fig.1, the design illustrating some of the difficulties involved. The sampling nozzle must be long to avoid a disturbance being created upstream of the tip. The use of a water jacket has disadvantages. On their passage through the sampling tube the gases are cooled, causing a decrease in velocity. This means that the fume particles are more likely to be deposited along the tube due to gravity settling and thermal precipitation. Also, if the gases are cooled below their dew point, condensation will occur. To keep the velocity of the gases as high as possible the cross-sectional area of the sampling tube is decreased as the gases are cooled, whilst, to minimize the cooling, an air gap is provided between the sampling tube and the water jacket for most of its length.

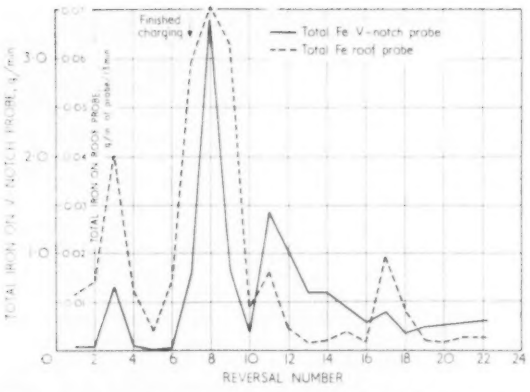
To study the effect of changes in furnace operation without the difficulties encountered in setting up an isokinetic sampling system in the downtake, an impact probe was designed (*see* Fig.2). This collects the fume by impact in a 120° V-shaped cavity placed across the stream of hot fume-laden gases. It can, of course, only be used where the direction of flow is downwards, the collected material being then held in place by gravity. Unfortunately, the efficiency of collection of such a sampling device varies with particle size, its tendency being to collect more of the coarse material than the fine. With the estimated size distribution of fume from an OH furnace, the collection efficiency is only about 20%. A further possible disadvantage is that the results are a function not only of concentration but of velocity.

A technique has also been developed[4] which enables the relative deposition rates of iron oxide on the furnace roof to be rapidly determined with a minimum of interference with production. It consists of inserting a series of sintered-alumina thermocouple sheaths through ½-in. dia. holes in selected roof bricks so that they protrude 2 in. beyond the inner face. Within a few minutes the probes become stained with iron oxide. Figure 3 shows, on the right, a probe from the incoming end and on the left, one from the out-going end of a furnace roof. Both probes were left in the furnace for 5 min, but whereas the iron oxide has soaked right through the probe placed at the outgoing end, the one placed at the incoming end is relatively clean. Quantitative values for the rate of deposition of iron oxide can be obtained by cutting off a measured length of the probe tip and analysing for total iron; normally the middle inch of the 2-in. section is used for this purpose.

To obtain continuous records of the extent of fuming over a considerable number of heats a photo-electric smoke density meter has been used. This



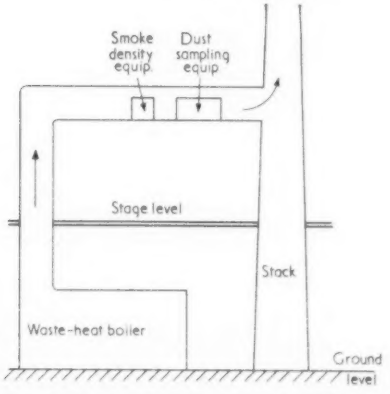
4 *Comparison of the weight collected on a* V*-notch probe in the downtake and readings of a smoke density meter in the stack*



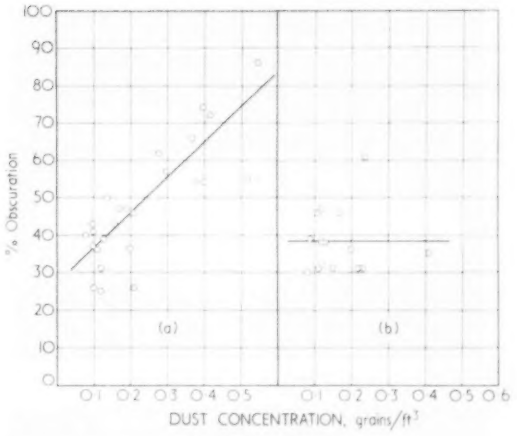
5 *Comparison of total iron collected on the* V*-notch probe and total iron deposited on an alumina probe in the roof*

consists of a lamp house and photocell built into the opposite sides of the furnace stack or some part of the waste-gas flue. A beam of light from the lamp house is directed across the stack and its intensity measured by a photocell. When the stack is clear the photocell gives its maximum signal but the value decreases with an increase in the amount of fume passing between the light source and the cell. The apparatus can be calibrated using neutral density filters so that it gives a reasonable measure of the attenuation of the light. However, since the obscuration by a given mass of dust depends on the particle size the measurements obtained with the smoke density meter can only be used as a qualitative estimate of the amount of dust passing the measuring point.

During several trials attempts have been made to see whether the results obtained by the different methods show the same pattern of events. During earlier trials on a pitch-creosote furnace eleven samples were taken from the downtake with the V-notch probe. Figure 4 shows the rate of deposition of material on the probe plotted with reversal averages of smoke density meter readings obtained simultaneously. There is fair agreement except during refining when droplets of slag are blown over which would not be expected to reach the stack where the smoke density was being measured. A second trial was also carried out with this probe during which 31



6 *Diagram showing position of equipment relative to stack*

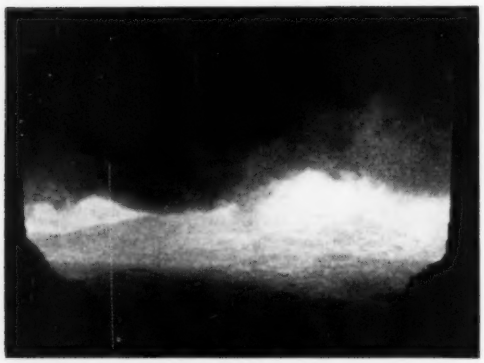


7 *Smoke density* v. *dust concentration*

samples were taken from one downtake only during charging and melting. As far as possible, two samples were taken during each reversal so that changes during reversals could also be examined. The weights of the probe samples were in reasonable agreement with the smoke density meter readings although there was a tendency for the smoke density meter to read low when the particle size of the probe sample was coarse. When an approximate correction was made for the coarseness of the material collected the agreement with the smoke density meter was much better.

The agreement between total iron collected with a V-notch probe and simultaneously with an alumina probe inserted in the roof has also been tested. This particular experiment was carried out on an oil-fired furnace and, as can be seen from Fig. 5, the peaks of both curves coincide, both registering the highest fuming rate just after the end of the charging period. However, the iron content of the material reaching the roof was higher during charging than refining, whereas the V-notch probe samples showed the reverse. This is probably because the iron oxide fume is fine and the efficiency with which the V-notch probe collects this is low, whereas slag particles are almost invariably coarse, and are mostly collected by the V-notch probe, but are unlikely to reach the roof.

Recently measurements have been made on an oil-fired furnace to determine the fume content of the waste gases in the chimney stack and also to check how closely the smoke density meter used in previous trials agreed with gravimetric samples obtained simultaneously by BISRA.[3] Figure 6 shows the positions where the equipment was installed. Before use the smoke density meter was calibrated over the whole of its range by neutral density filters so that it read the obscuration of light to an accuracy of 1%. A record of smoke density was obtained during eight consecutive heats. Strong similarity was found between the pattern of events during the different heats: the majority of the fuming took place between charging and melting periods, and on one occasion obscuration reached a level of 97%. During refining the smoke density was almost steady at a level of between 25–30% obscuration. The fume was also



(*a*) Carbon content of bath, 0·37%

(*b*) Carbon content of bath, 0·11%, 45 min after (*a*)

8 *Fume in OH furnace during oxygen blowing through adjacent door*

sampled isokinetically at a point about 10 ft downstream from the smoke density meter. Concentrations determined from these gravimetric samples have been plotted against obscuration in Figs.7*a* and *b*. It can be seen that a very good correlation was found for the charging and melting periods, but that during the refining period, there was no correlation at all. This suggests that the particle size is more variable during the refining period, but since no measurements of particle size were made this explanation is merely conjectural.

FACTORS AFFECTING FUMING

Oxygen lancing

One of the most striking cases of iron oxide fuming occurs when oxygen is injected into the bath during the refining period. Anyone standing outside the melting shop is soon aware that blowing has begun by the large quantities of red-brown fume given off from a stack that previously emitted little visible material. Several years ago some experiments were made to see the effect of oxygen and air injection on the rate of carbon removal in a cold-charged OH furnace fired with oil. During oxygen injection dense iron oxide fumes were produced. When air was used there was also heavy fuming but much less than with oxygen injection. This difference in fuming rate could be seen quite clearly through the furnace doors as well as from the appearance of the plume from the chimney stack.

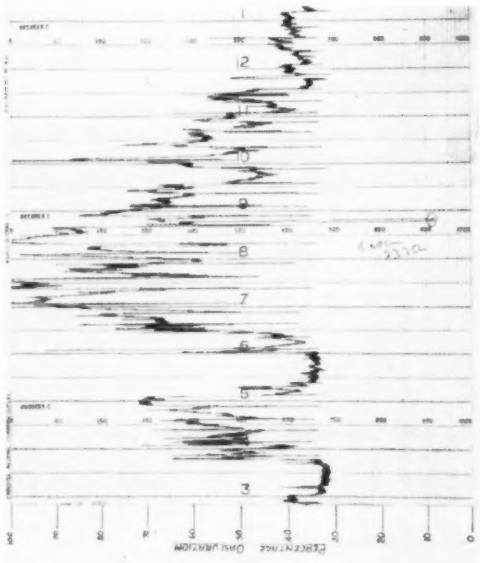
It was also noted during these trials that as blowing proceeded and the carbon content fell the fuming decreased. Figure 8 shows two photographs taken through the door of the furnace during the same blowing operation. In (*a*) the carbon content was 0·37% whereas in (*b*) taken three quarters of an hour later, the carbon content was only 0·11%. It can be seen that there is markedly less fume when the carbon content of the bath has fallen. However, the amount of fume produced did not appear to be a function of carbon content only, since in different casts different amounts of fume were formed even when the bath had the same carbon content.

Recent measurements on a hot-metal shop,[5] also showed this tendency for fuming to decrease as blowing of oxygen proceeds. The tests, unfortunately, only included one blowing period of an hour when oxygen was blown through hand lances at the rate of 35 000–40 000 ft³/h. During this limited period, isokinetic sampling showed that the weight of dust leaving the chimney stack dropped from 480 to 460 lb/h. The experiment was made during melting when, with normal operation, the weight of dust leaving the chimney stack, calculated on the basis of only a few samples, would be about 40 lb/h.

Type of fuel

During the late 1940's when several firms were converting their furnaces from producer-gas to pitch-creosote firing a great deal of trouble was experienced from excessive iron oxide fuming. Large amounts of iron oxide were carried over into the downtake and, in many cases, furnaces had to be taken off after only six weeks operation to clean out the bottoms of the checkers and flues. During this period a series of experiments was carried out on two 80-ton cold-charged fixed furnaces fired with pitch creosote.

To obtain a continuous record of the extent of



9 *Typical record of obscuration from tap-to-tap for a pitch-creosote-fired furnace*

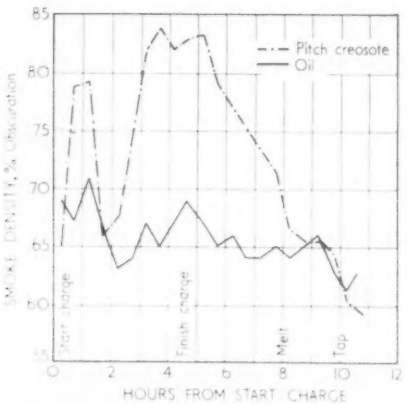
fuming over a large number of heats a photoelectric smoke density meter was built into the chimney stack of one of the furnaces. It was hoped that the results would enable the group to ascertain whether there was a definite pattern of events, e.g. did fuming always occur at the same stage and was it associated with some particular roof temperature or some particular charged material. Figure 9 shows a typical record obtained with the smoke density meter during a pitch-creosote heat. The characteristic fuming peak just after the end of the charging period can be clearly seen. Figure 10 shows the results obtained on a large number of heats firing with pitch creosote and with oil, and illustrates the difference in fuming rates.

During these trials samples were also collected from the downtakes by means of the V-notch probe and one set of measurements is shown in Fig.4. Chemical analysis confirmed that the chief cause of choking of the slag pockets and checkers was excessive iron oxide carry-over, mainly Fe_3O_4, though most samples contained some FeO and some contained small quantities of Fe_2O_3.

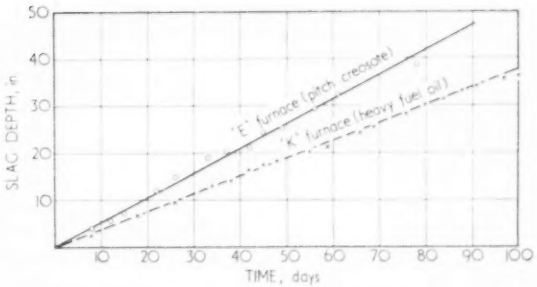
The effect of pitch creosote (pc) on fuming was also studied on 300-ton hot-metal furnaces where it was used in conjunction with coke-oven gas. Normally the ratio of pc to coke-oven gas was 1 : 3 on a thermal input basis, but during these trials the effect of switching off the pc altogether, while keeping the heat input constant, was examined. The effect of this experiment on the fuming rate was measured using the alumina probe technique and in all 25 pairs of observations were made with pc 'on' as against pc 'off'. It was found that when pc was used with the coke-oven gas there was about three times (3·2) as much iron oxide deposition on the probes as there was without pitch creosote.

During this series of tests the effect of 30 000–40 000 ft^3/h of combustion oxygen was also studied. It was found that combustion oxygen reduced the amount of fume collected by a factor 2·5.

During the past few months the author's group has been trying to measure the collection efficiency of slag pockets. The few results obtained again illustrate the difference, in quantity of material carried over, between pc and oil-firing. Figure 11 shows the rate of



10 *Comparison of pitch creosote and oil, variation in smoke density throughout the cast cycle*



11 *Slag depth* v. *time for a pitch-creosote and a heavy fuel oil fired furnace*

rise of the slag level in two furnaces, one fired with pc and the other with heavy fuel oil, which illustrates this. It was estimated that about 50% of the total solids burden in the waste gases was collected by the slag pocket. As the final level of the slag is usually within 2 ft of the top of the slag pocket it is surprising that the rate of deposition in the slag pocket was uniform indicating that the efficiency of collection did not decrease during the campaign. An examination of the slag heights of five furnaces fired with pc compared with seven furnaces fired with heavy fuel oil showed that the slag pockets of the pc fired furnaces collected about 1·4 times as much as the heavy fuel oil fired furnaces. However, a comparison of the relative rates of flow of material in the downtake indicated that the relative waste-gas solids burdens for pc and oil-fired furnaces were in the ratio of about 1·75 : 1. This suggests that the slag pocket collection efficiency for a pc fired furnace is less than for an oil-fired furnace, probably because the particle size of the dust burden with pc is generally smaller.

Steam/fuel ratio

The effect of varying the steam/fuel ratio was examined on an 80-ton cold-charged furnace fired with pc. A series of tests was carried out during two heats in which the steam/fuel ratio was studied alternately at 7 lb/gal and 5 lb/gal during each reversal. Two samples were taken with the V-notch probe during each reversal, one with the high and the other with the low steam flow. The trials were encouraging because in all cases but one the change from low to high steam flow gave a significant reduction in the deposit obtained in spite of an increase in burner thrust.

Similar trials were also made on a 300-ton hot-metal furnace fired with a mixture of pc and coke-oven gas. The deposition rate on alumina probes inserted through the roof was used as an indication of the amount of fume evolved. Increasing the steam/pitch ratio from 7 : 1 to 10 : 1 reduced the fuming by about 40%. The effect of the same variations in steam flow was examined with coke-oven gas only, although it is realized that steam would not normally be used in conjunction with coke-oven gas. It was interesting, however, to note that the higher steam/fuel ratio gave 30% less fume than the lower one.

It would appear, therefore, that any method of increasing the rate of combustion either by the use of combustion oxygen or increasing the steam/fuel ratio will help to reduce fuming.

TABLE I Comparison of iron oxide deposits of 375 gal/h single burner and 500 gal/h twin burners

	Deposition rate on probe, g of iron × 10^6 /in./min
Peak fuming rate	
1 Areas of excessive wear	
(*a*) 375 gal/h	70
(*b*) 500 gal/h	400
2 Areas of normal wear	
(*a*) 375 gal/h	30
(*b*) 500 gal/h	200
General level of fuming, late melting down and early refining	
1 Areas of excessive wear	
(*a*) 375 gal/h	5
(*b*) 500 gal/h	9
2 Areas of normal wear	
(*a*) 375 gal/h	4
(*b*) 500 gal/h	5

TABLE II Comparison of iron oxide deposits for 100-ton cold-charged and 300-ton hot-metal furnaces

	Deposition rate on probe, g of iron × 10^6 /in./min
Peak fuming rate	
1 Areas of excessive wear	
(*a*) 300-ton hot metal	300
(*b*) 100-ton cold metal	70
2 Areas of normal wear	
(*a*) 300-ton hot metal	80
(*b*) 100-ton cold metal	30
General level of fuming, late melting-down and early refining	
1 Areas of excessive wear	
(*a*) 300-ton hot metal	100
(*b*) 100-ton cold metal	5
2 Areas of normal wear	
(*a*) 300-ton hot metal	30
(*b*) 100-ton cold metal	4

Fuel quantity

An attempt has been made to evaluate the effect of fuel quantity by comparing two similar 100-ton cold-charged furnaces in the same melting shop and working to essentially the same programme. Both were oil-fired, one with a single burner at a maximum rate of 375 gal/h and the other with twin burners at 500 gal/h. Table I shows typical values for the rate of deposition of iron oxide on an alumina probe, expressed in units of iron per inch of probe, for these furnaces under various conditions.

These represent the averages of many readings but even so because of traces of iron already present in the probes the accuracy for the small deposits is not better than 10%. It can be seen that when firing with 500 gal/h with twin burners almost six times more iron oxide is deposited on the probes during peak fuming than when the furnace is fired at its usual rate of 375 gal/h. It may be, however, that the flow pattern across the bath is, as might well be expected, an influential factor in determining the deposition rate of iron oxide at the roof so that twin burners may themselves be partly responsible for the increase in iron oxide deposition.

Type of practice

In hot-metal practice the proportion of pig iron used can be more than double that in cold-metal practice, and this may be an important factor in deciding the differences in fuming rate. There are obviously other differences in the way the furnace is fired and the way the charge is worked and these may also be important.

Over the past few years a considerable number of iron oxide samples have been collected by the alumina probe technique from 100-ton cold-charged furnaces, oil-fired by a single burner at 375 gal/h, and from 300-ton hot-metal furnaces, fired with twin burners with 125 000 ft^3/h of coke-oven gas and 120 gal/h of pc. Both types of practice give a fuming peak: on the cold-charged furnaces it occurs at about the end of charging, whilst with hot-metal practice it occurs towards the end, or just after, the first addition of hot metal. The results obtained with these two types of practice are compared in Table II.

It can be seen that during peak fuming on the hot-metal furnace an area of excessive wear receives iron oxide, expressed in units of iron per inch of probe, at the rate of 0·03 g/min. This is four times the rate of deposition experienced in a similar position on a cold-charged furnace fired at the usual rate of 375 gal/h. However, the results in Table I suggest that the extent of fuming also depends on firing rate, but even so the general level of fuming with hot-metal practice was considerably higher than that measured with cold-metal practice with either fuel input. Another factor which makes the comparison difficult is that the hot-metal furnace was fired with a proportion of pc which, as has already been pointed out, accentuates fuming.

Effect of metalloids

In the OH furnace the rate of fuming decreases as the carbon in the bath is reduced. For example, peak fuming always occurs when the carbon in the bath is high; at the beginning of the refining period in hot-metal practice or during early melting-down in cold-metal practice. Also during bath injection of oxygen it was noted that as blowing proceeded and the carbon content of the bath fell the rate of fuming decreased. The effect of carbon and other metalloids on the formation of fume has, therefore, been examined by BCIRA[6] and ourselves, and more detailed work is at present being carried out by BISRA. The results obtained by BCIRA are presented in Table III. Two grams of each specimen in the form of drillings were heated in a combustion tube to a temperature of 1 180°C and a stream of oxygen was then passed over them. The silicon, phosphorus, and sulphur alloys were substantially carbon free and produced a negligible amount of fume, whereas the sample con-

TABLE III Effect of metalloids on fuming

Main alloying element(s)	Fume observed
1·5%Si	None
1·0%P	Very slight white fume for a few seconds
1·5%Si + 1·2%P	Very slight white fume for a few seconds
0·4%S	None
3·9%C	Dense brown fumes

TABLE IV Effect of metalloids and temperature on fuming

Sample	% Main alloy	Temperature, °C	Fume	Temperature, °C	Fume	Temperature, °C	Fume
Ferro-phosphorus	27·2%P	1 100	Nil	1 200	Light white	1 300	Light white
Ferrosilicon	75%Si	,,	Nil	,,	Nil	,,	Nil
Swedish white iron	3·5%C	,,	Dense brown	,,	Dense brown	,,	Medium brown
Graphitized chill iron	3·8%C	,,	Light brown	,,	Dense brown	,,	Medium brown
Mild steel	0·18%C	,,	Short, light brown	,,	Short, light brown	,,	Short, light brown

taining 3·9% of carbon and only a small proportion of other elements produced dense brown fumes. This work has been extended in an attempt to evaluate the effect of the temperature of the sample as well as its analysis.

Table IV summarizes the first results obtained with ferro-alloys at 1 100°, 1 200°, and 1 300°C.

Again only the alloys containing carbon gave any noticeable fume. The most noteworthy result was the difference in fuming observed between Swedish white iron and graphitized iron at the lower temperature. This may have been because the carbon in the white iron is in the combined form, whereas in graphitized iron it is, for the most part, free carbon. However, the graphitized iron contained 1%Si and it may be that this in some way helps to suppress fuming. The absence of fume from the ferro-alloys may be due to the metalloids being oxidized in preference to the iron, or it may be that the alloying element forms a slag which protects the iron from the oxygen. In the case of the ferro-phosphorus a protective slag may have been formed from reaction products with an alumina boat which was severely attacked. Eleven other samples containing varying amounts of carbon and other elements have now been made for United Steels by BCIRA and more closely controlled tests are being carried out on these.

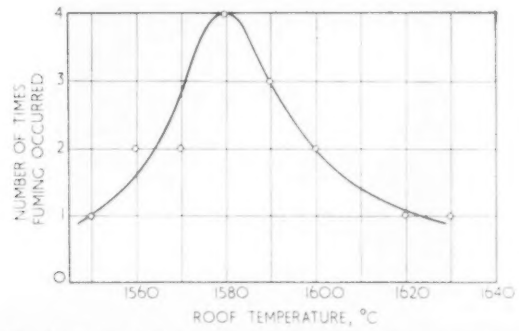
BISRA[7] have also investigated the influence of metalloids and found that molten iron or iron alloys containing no carbon produced no fuming when held in a stream of oxygen, whereas with molten iron–carbon alloys fumes were evolved.

PHYSICAL CHARACTERISTICS OF OH FURNACE FUME

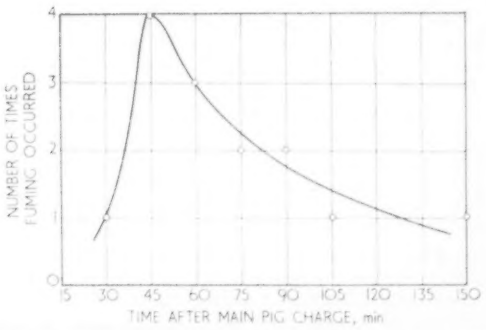
As has already been stated fuming almost invariably occurs in cold-metal practice at the end of the charging period when the scrap is beginning to melt, and in hot-metal practice at about the end of the first hot-metal addition. This suggests that there is some critical temperature associated with heavy fuming. To check this a considerable quantity of data was collected during eight consecutive days' observations on a cold-charged, pc fired furnace. It was found that the heavy fuming always occurred within a very narrow range of roof temperature. It can be seen from Fig.12 that no heavy fuming was observed below 1 550° or above 1 630° C and in 11 of the 16 cases examined it occurred between 1 570° and 1 600° C. It would appear, therefore, that the temperature range in which peak fuming occurs is very small indeed. Of these 16 cases of peak fuming 14 took place between the main charge of pig iron and the next round of charging and Fig.13 shows these 14 plotted against the time which had elapsed after the pig iron had been charged. It can be seen that in the majority of cases heavy fuming occurs between 45 and 90 min after the main pig charge; only two occur outside that range. It can be stated, therefore, that heavy fuming is not likely to take place with the roof temperature below 1 550° or above 1 630° C and that it is most likely to occur $\frac{3}{4}$–1$\frac{1}{2}$h after the main burden of pig iron has been charged. It may be, however, that these two factors are interrelated and that one of them is incidental.

Kohlmeyer,[8] investigating the effect of blowing air and oxygen on iron–carbon melts, did in fact find that fuming did not start before the surface was at a temperature of 1 170°C, i.e. just above the melting point of the iron–carbon melt, and was at a maximum at about 1 400°C. When the temperature of the melt exceeded 1 500°C fuming ceased. The evidence of these laboratory experiments and the works data suggest therefore that heavy fuming is most likely to occur when the bath temperature is about 1 400°C.

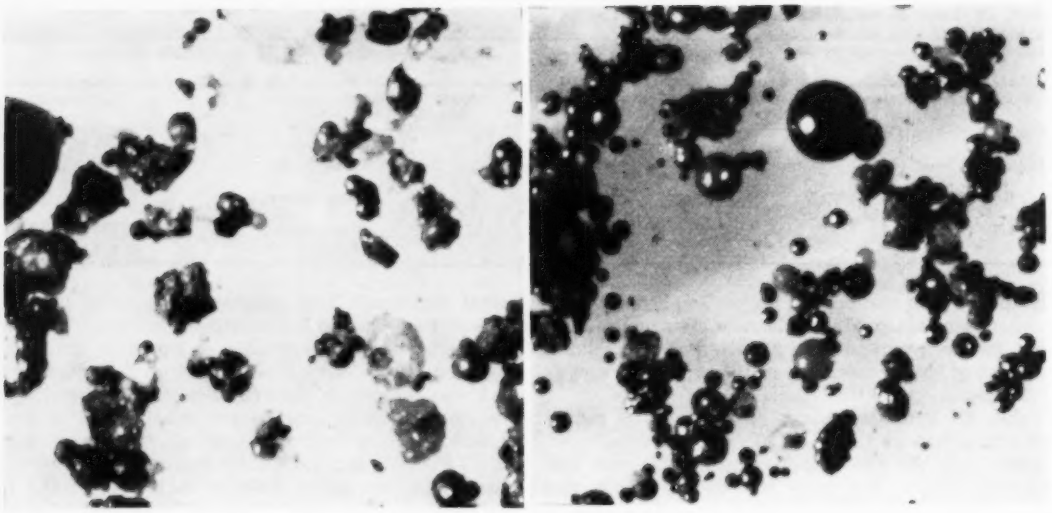
The structure of the fume may provide some



12 *Variation of frequency of fuming with roof temperature*



13 *Variation of frequency of fuming with time after the main pig charge*

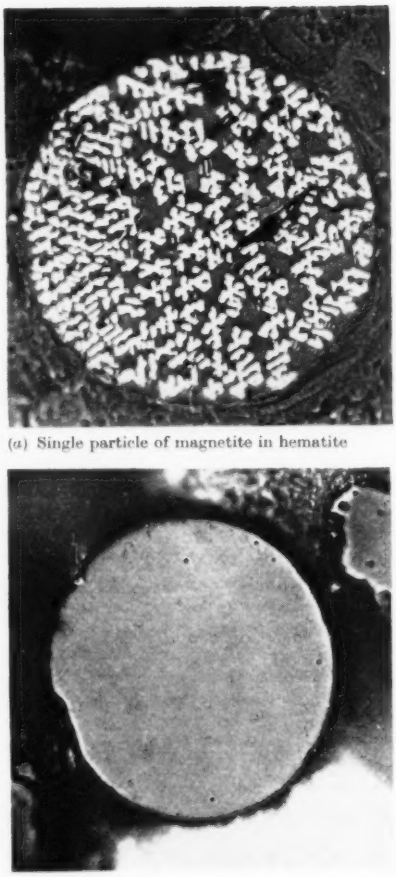


(*a*) Heavy fuel oil firing (*b*) Pitch-creosote firing

14 *Samples collected during the charging period* ×100

evidence of the way in which it has been formed. Many samples have therefore been collected with the V-notch probe for chemical and physical examination. One of the advantages of the V-notch probe is that the material collected is immediately chilled and therefore has little chance to agglomerate, and also, it is not mixed up with glass- or asbestos-fibre so that examination of individual particles is reasonably easy. Figure 14 shows two such samples, collected during the charging period, one from a furnace fired with heavy fuel oil and the other from a pc fired furnace. It was found that, in general, the samples collected when firing with fuel oil were coarser than when firing with pc. For heavy fuel oil the particles varied from 150 μ (0·15 mm) downwards with very few particles below 25 μ. On the other hand with pc very few particles were larger than 100 μ and the majority were below 50 μ. Figures 15 and 16 show cross-sections of individual particles, collected during the charging period, under a high magnification. In general it was found that the particles collected from the oil-fired furnace were composed of a primary solution of magnetite in hematite (Fig.15*a*), with occasional particles of hematite (Fig.15*b*), while from the pc fired furnace separate particles of magnetite and wüstite (Fig.16*a*) were obtained. This difference in composition is probably because in the pc fired furnace the atmosphere was more reducing than in the oil-fired furnace. It can also be seen, Fig.16*b* is an outstanding example of this, that when firing with pc the particles were much more porous than when firing with oil.

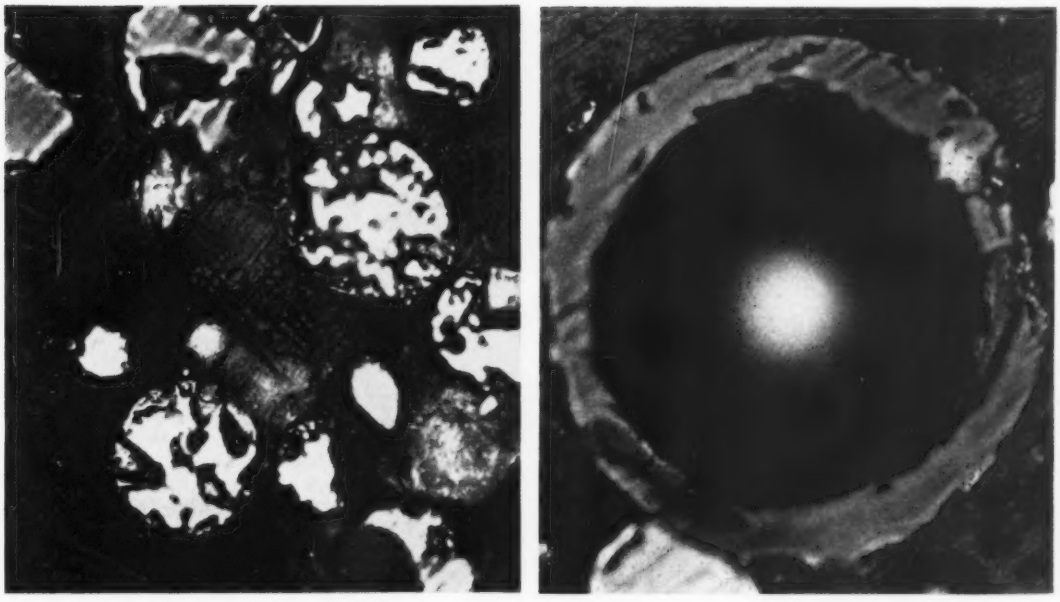
Several of the samples collected from the stack by BISRA were also examined on the electron microscope and Fig.17 gives four typical examples of the photographs obtained. The particle shapes examined fell into two categories: spherical or polyhedral, which included rods, cubes, and hexagons. The size distribution of the fundamental particles, as distinct from agglomerates, varied among the samples taken at different stages of the heat. During charging and



(*a*) Single particle of magnetite in hematite

(*b*) Single particle of hematite

15 *Fume collected during late charging, heavy fuel oil firing* ×750



(*a*) Particles of magnetite and wüstite

(*b*) Single hollow particle of wüstite

16 *Fume collected during late charging, pitch-creosote firing* × 750

refining all particles examined were in the range of about 0·2–1·0 μ. This was also a predominant range at other stages of the heat, but there were some very fine particles down to 0·01 μ during the peak fuming period, which occurred at the beginning of the melting-down period, and some larger particles up to 5 μ during peak fuming and the late melting-down period.

CONCLUSIONS

The amount of carbon present in the bath appears to have a strong influence on the rate of fuming. Experiments in the laboratory confirm this.

The type of fuel also appears to have an effect and again carbon may be the influential factor; pc, which contains more carbon than fuel oil, giving more fume.

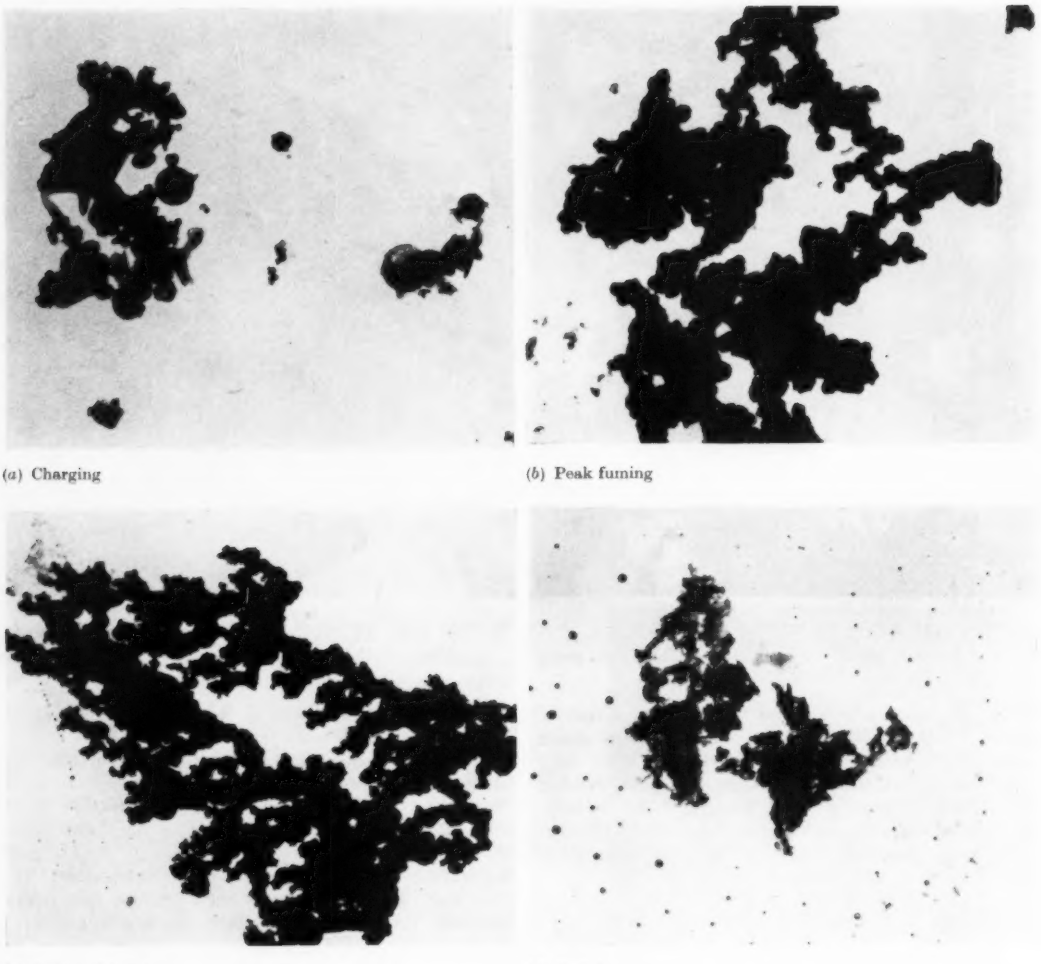
Increasing the rate of combustion either by the use of a higher steam/oil ratio or combustion oxygen, reduces the fume. This might be attributed to a reduction in the amount of free carbon in the flame.

Heavy fuming usually occurs at about the end of the charging period. With cold-metal practice the roof temperature at this time is about 1 600° C and the charge temperature is estimated to be 150–200°C lower. With hot-metal practice it is estimated that fuming occurs when the bath temperature is higher than 1 300°C. Laboratory experiments also suggest that there is a critical temperature range for the charge, around 1 400° C, at which fuming is most pronounced.

Because of the bath temperatures involved the vapour pressure of iron is too low to account for the quantity of fume evolved even if allowance is made for the increased vapour pressure of the droplets just above the surface of the bath. Kosmider, however, has postulated that fuming during Bessemer blowing can be attributed to the evaporation of iron, the high rates of evaporation being explained on the basis of very high local temperatures.

There are many other cases of unexplainable losses of metals, for instance, silver, gold, or silicon, which cannot be accounted for by the magnitude of the vapour pressure. In these cases it has been shown that an intermediate compound, e.g. Ag_2O, AuCl, having an abnormal volatility, is responsible. It is not easy to detect these intermediate compounds because they may dissociate on condensation or enter into secondary reactions. Some years ago Kohlmeyer[8] put forward a theory to try to explain the results of his laboratory experiments. He assumed the existence of iron carbonyl, FeCO, formed by combination of FeO with Fe_3C. The FeCO thus formed being unstable, would immediately break down in the furnace to form carbon monoxide and iron vapour which would then be oxidized to form iron oxide fume. However, Kohlmeyer observed no evaporation when carbon monoxide was blown on to a melt in the temperature range 1 300–1 460°C. If iron carbonyl is readily formed in this temperature range then some evaporation must be expected and, in the absence of a satisfactory explanation of this, the validity of the theory must be in doubt. Other workers have proposed a fluoride theory in which the iron is volatilized from the bath as an iron fluoride which is then decomposed. This theory falls down because most of the fuming occurs well before fluorspar is added to the bath and also occurs when fluorspar is not used at all.

In the case of the fuming of iron it could well be that certain combinations of iron and wüstite are much more volatile than pure iron. It is well known that the solution of impurities in a liquid lowers its surface tension and that as the surface tension decreases the vapour pressure increases. It has also



(*a*) Charging

(*b*) Peak fuming

(*c*) Late melting-down

(*d*) Refining

17 *Electron microscope photographs of fume collected from the stack of an oil-fired furnace* – 10 000

been found that small amounts of oxygen markedly lower the surface tension of liquid metals and in the case of iron an addition of 0·1 wt-%O_2 reduces the surface tension by over 40%. This decrease of surface tension, with the consequent increase in vapour pressure, will, however, only occur for oxygen in solution and when a compound is formed, e.g. Fe_3O_4, the vapour pressure will most certainly decrease. This may explain the importance of carbon in that it is constantly combining with the iron oxide formed on the surface producing a layer of a lower oxide content with a higher vapour pressure. It may also be significant that the critical temperature given by Kohlmeyer is, in fact, just a little higher than the melting point of wüstite. The production of a more oxidizing atmosphere close to the bath by the use of higher steam/oil ratios or combustion oxygen, may also be explained in that it increases the oxidation rate at the surface beyond the critical value. This, therefore, is a possible, though probably not the only theory explaining all the facts. Whatever be the mechanism of fume formation there is no doubt that it can be substantially reduced by improving combustion conditions.

ACKNOWLEDGMENTS

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A study of the solution rate of iron in liquid bismuth from a number of ferritic steels

L. W. Graham, B.Sc., Ph.D., L.I.M., and G. W. Wilson, B.Sc., Ph.D., A. Inst.P.

SYNOPSIS

A series of experiments measuring the rate of solution of iron from five ferritic steels in liquid bismuth at 550°C is described together with an investigation of the effect on this solution rate of 200 ppm of zirconium added to the liquid metal. Mechanisms explaining the reduction in the solution rate observed with increasing chromium content of the steels and also the decrease in solution rate and apparent solubility in bismuth containing zirconium are proposed. In the former case the solution rate appears to be governed by the rate of passage of solute atoms across the solid/liquid interface. The effects of the zirconium appear to be consistent with either a reduction in the actual solubility of iron in a bismuth–zirconium solution or the formation of a compound layer on the steel surface. 1613

INTRODUCTION

ONE OF THE MAJOR DIFFICULTIES associated with the use of many liquid metals as heat transfer media is the finite, though small, temperature-dependent solubility of most container materials[1] at temperatures in the range 400–600°C. Thus, as indicated in previous papers,[1–3] steels used in experimental heat exchanger systems suffer from attack and mass transfer by liquid bismuth, particularly under the temperature gradients existing in such environments. It appears possible that this attack can be reduced to acceptable limits by adding inhibitors, particularly zirconium, to the liquid metal.[2, 4]

The rate of solution of the solute is one of the major factors controlling the behaviour of steels containing liquid bismuth under non-isothermal conditions. The present investigations were undertaken to measure this rate for iron, chromium, and nickel from a number of steels at 550°C. Two series of experiments were carried out, the first with a range of steel compositions as in Table I and using pure liquid bismuth, the second using one steel, and bismuth containing zirconium after pretreatment of the steel with bismuth–zirconium.

MATERIALS

The specimens were machined from normalized and tempered steel bar and for experiments using pure bismuth were in the form of cylinders 0·25 in. dia. and 0·75 in. long. Investigations using bismuth containing 200 ppm of zirconium were carried out using steel crucibles 0·30 in. dia. and 0·80 in. long, with a cavity 0·25 in. dia. and 0·75 in. deep.

To reduce the oxygen in the bismuth to a very low level, the metal was vacuum melted, soaked at 550°C, cooled to 300°C, and filtered. Zirconium was dissolved in some of the bismuth during this treatment, subsequent filtering being carried out at a higher temperature, i.e. 400°C. Samples were taken from three portions of each rod and analysed for iron, chromium, nickel and, where applicable, zirconium. The results of these analyses are indicated in Table II.

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The authors are with the Hawker Siddeley Nuclear Power Co. Ltd.

TABLE I Composition of steels examined

Firth-Brown reference	Composition determined by analysis, % C	Cr	Mn	Mo	V	W	Ni
MOVA1	0·12 max.	0·26	0·48	0·75	0·44	...	0·25
CRMO	0·12 ,,	0·81	0·48	0·62	...	...	0·11
CRM6	0·15 ,,	2·1	0·49	0·84	...	...	0·13
CRM5	0·12 ,,	4·8	0·38	0·62	...	...	0·14
CHROMVA-W	0·17 ,,	2·74	0·45	0·63	0·88	0·37	0·22

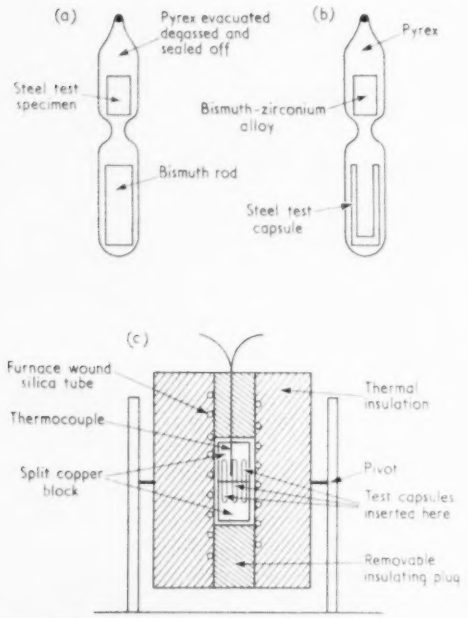
Experimental techniques

The steel samples and the bismuth were sealed in evacuated Pyrex capsules, the amount of bismuth employed in the experiments where it contained no zirconium being standardized at 10·00±0·01 g and for the zirconium containing bismuth at 5·60±0·01 g. The capsules were constructed to allow vacuum outgassing at 500°C before sealing, without allowing contact between the liquid metal and the steel. The construction of the furnace in which the interaction between the steels and the bismuth was carried out allowed six capsules to be reacted simultaneously, each capsule being seated in an appropriate position in a split copper block. In practice the reactants were brought up to temperature, 550±3°C, and were then contacted by inverting the furnace, the reverse procedure being adopted to separate the reactants after any desired period of time. The steel cylinders were held below the surface of the bismuth during reaction

TABLE II Composition of bismuth used in experiments

	Composition, ppm Fe	Cr	Ni
Average	3	3	2
Maximum	5	5	5
Minimum	1	1	1

Only one cast of bismuth–zirconium alloy was used and this contained 200±10 ppm of zirconium

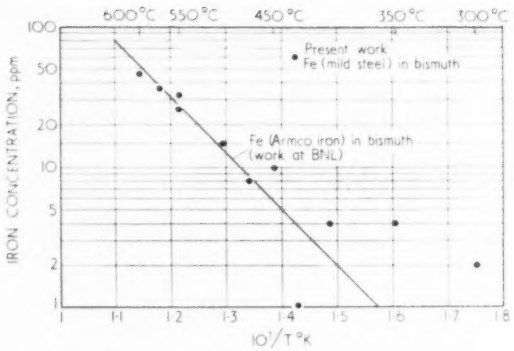


(*a*) **Capsule used in tests with pure bismuth**
(*b*) **Capsule used in tests involving bismuth–zirconium**
(*c*) **Furnace arrangement**

1 *Experimental technique*

by means of a constriction in the Pyrex capsule. The experimental technique is shown in Fig.1.

In the experiments using zirconium containing bismuth, the Pyrex had to be prevented from contacting the liquid metal with which it slowly reacted. In this case therefore, the glass was shrunk on to the steel crucible so that the liquid metal was prevented from touching the glass except for brief periods at the beginning and end of each experiment. Pretreatment of the inner surface of the steel was carried out by reacting it with a standard amount of bismuth–zirconium for 72 h at 550°C and then separating the reactants, cooling down, and remaking the capsule with a fresh supply of the alloy.



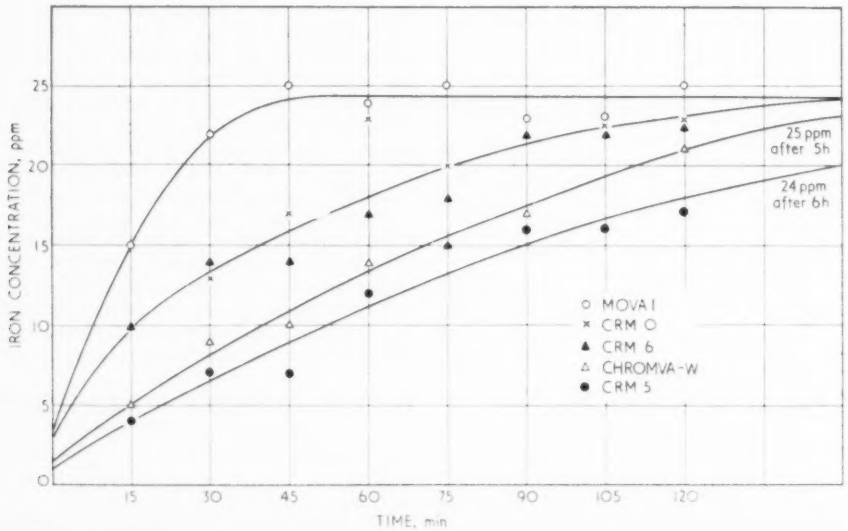
2 *Solubility of iron in bismuth*

After removal from the capsules the bismuth ingots were analysed, the whole of the sample being dissolved to preclude any error due to sampling.

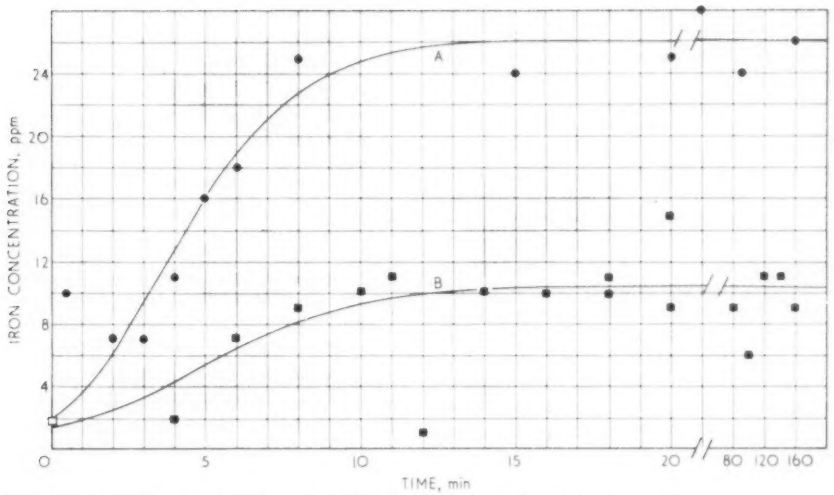
Experimental results

The solubility of Armco iron in liquid bismuth has been reported by workers at Brookhaven National Laboratory.[2] To check the technique adopted in the present work the solubility of iron (mild steel) in bismuth was determined in the temperature range 300–600°C. The results are compared with the US data in Fig.2.

The results concerning the solution rate of iron from the steels examined in pure bismuth are presented in Fig.3. Within experimental error the limiting iron concentration attained was 25 ppm in all cases, although it is evident that increasing the chromium content of the steels up to 5% results in a marked reduction in the rate of solution of the iron. The solution-rate curves for the iron appear to conform to an equation identical to that used for analysing the



3 *Solution rate of iron in pure bismuth*



4 *Solution rates in pure bismuth, A, and in bismuth containing zirconium after pretreatment, B*

solution rate of copper in liquid bismuth and liquid lead.[5]

$$N_t = N_o\,(1-\exp-kst/v)$$

where N_t = concentration after time t, N_o = saturation concentration, s = surface area of the specimen in contact with liquid, v = volume of bismuth, k = solution-rate constant.

In the case of the experiments using MOVA1 steel crucibles the technique was first checked by using pure bismuth, the results thus obtained and those measured in bismuth containing zirconium after pretreatment are shown in Fig.4. In the latter case not only is the solution rate decreased but also the apparent solubility of the iron in the bismuth, thus even after 160 min the solubility is about 10 ppm as compared with 25±1 ppm using pure bismuth. The results in Figs.3 and 4 have been analysed in terms of the equation giving the values of the solution rate constant k presented in Table III. The difference between the value found for MOVA1 in pure bismuth using the two different types of specimens is almost certainly due to errors in the values assumed for the surface area of the specimens as no account was taken of surface roughness.

All the values obtained for the nickel and chromium contents found in the bismuth after separation of the reactants lay in the range 3±3 ppm. Although it is not possible to state whether the constituents are removed from the steels in stoichiometric proportions, it is evident that marked preferential solution of these elements does not occur during reaction times sufficiently prolonged to allow the iron to reach the equilibrium concentration.

TABLE III Experimental values for solution-rate constant k

Material	Form of specimen	Liquid metal	k, cm/s
MOVA1	Solid rod	Pure bismuth	$2{\cdot}8\times10^{-4}$
CRMO	" "	" "	$1{\cdot}0\times10^{-4}$
CRM6	" "	" "	$1{\cdot}0\times10^{-4}$
CHROMVA-W	" "	" "	$6{\cdot}1\times10^{-5}$
CRM5	" "	" "	$4{\cdot}2\times10^{-5}$
MOVA1	Crucible	" "	$4{\cdot}0\times10^{-4}$
MOVA1	" "	Bismuth–zirconium	$3{\cdot}7\times10^{-4}$

DISCUSSION

In general, the rate of solution of a solid in a liquid can be controlled by either (*a*) the rate at which solute atoms diffuse from the liquid boundary layer into the bulk of the liquid, or (*b*) the rate at which atoms pass from the solid into this liquid boundary layer.

If (*a*) is the rate-controlling step then the solution-rate constant $k = D/\delta$, where D is the diffusion coefficient of the solute in the solvent and δ is the thickness of the laminar boundary layer.[6] If (*b*) is the rate-controlling process then $k = \bar{\nu} n_s / N_o$, where $\bar{\nu}$ is a frequency factor and n_s is the number of atoms per unit area of specimen surface, N_o is the saturation concentration.

Ward and Taylor[5] concluded that the rate of solution in their experiments was controlled by process (*a*) combined with convection effects introduced by density changes occurring in the liquid accompanying this dissolution. The technique used in the present work is almost identical to that used by these authors and the results for iron from the five low-alloy steels in pure bismuth conform to the same equation. However, it is difficult to reconcile results reported here with rate-controlling processes involving diffusion through a laminar boundary layer.

The experiments described show that the solution rate of the iron is markedly decreased as the chromium content of the steel increases, even though the saturation concentration remains unchanged and the actual chromium content of the steels is small. It is therefore suggested that the decrease in the solution rate of the iron is due to either an interaction between the iron and chromium atoms in the solid which increases the energy required for atoms of the former to pass into solution, or the presence of oxide films on the specimens. The change in the nature of this oxide film with chromium content of the steel might account for the observed change in the solution rate due to the stability imparted by increasing proportions of chromium in this surface oxide.

The preceeding discussion has been confined to solution rates in pure bismuth. In the case of bismuth containing zirconium Fig.4 suggests that the saturation concentration N_o and the solution rate of iron is

decreased. However, Table III indicates that this reduction is accompanied by little, if any, significant change in the solution-rate constant provided that the apparently reduced value of N_o is used in its calculation. It is therefore suggested that the pretreatment of the steel specimens and the presence of zirconium in the bismuth does not appreciably affect conditions at the steel/liquid metal interface. In this case it is probable that the observed reduction in iron concentration is due to the influence of zirconium on the actual solubility of iron.

Additions of manganese or of nickel to solutions of uranium in bismuth are known to reduce the magnitude and temperature dependence of the solubility of uranium in bismuth.[7] This is due to a decrease in the entropy and heat of solution of the uranium in the liquid metal. However, the apparent decrease in solubility of iron in the presence of zirconium observed in the present investigation is many times greater than is the case with bismuth–uranium solutions with similar quantities of added elements.

The effect of additions of zirconium to bismuth in inhibiting attack and mass transfer in non-isothermal heat transfer systems is reported to be due to the formation of a very thin film of zirconium nitride on the steel surface.[2,4] If, however, such a film were formed during the course of the present work it would be expected to cause a considerable change in the solution-rate constant. Alternatively, if only parts of the steel were covered with zirconium nitride the apparent solution rate would be expected to decrease due to the decreased effective surface of the specimen and in the absence of any other mechanism the equilibrium solubility of iron in the bismuth–zirconium solution would not be reduced since the liquid metal would still be in contact with the steel although over a reduced surface area. It is possible, however, that the presence of areas of film may account for the scatter observed for some of the measured iron concentrations.

US workers[2] propose that the formation of the inhibiting film is preceded by the formation of an adherent surface deposit of an iron–zirconium intermetallic compound. Two compounds are known in the system: Fe_2Zr and Fe_3Zr. However, their experiments with a button of Fe_2Zr compound showed that both components dissolved to their normal solubility limits. Despite this, the result of the present work may possibly be due to the formation of a film of intermetallic compound on the surface of the steel, possibly Fe_3Zr stabilized in some way by the bismuth which is known to be capable of forming at least one intermetallic compound with zirconium. The maximum iron concentration of 10 ppm found during most of the experiments would then represent the equilibrium concentration of iron from this compound in bismuth containing zirconium at 550°C.

The present investigations were carried out at only one temperature. Their extension to other temperature ranges would enable the mechanism controlling the dissolution of the iron to be more fully assessed. Thus, if the activation energies found in the experiments with both bismuth and bismuth–zirconium were the same this would support the theory that the zirconium does not appreciably affect the steel/liquid metal interface.

CONCLUSIONS

The phenomena observed in the experiments described can be divided into two parts:

(i) the rate of solution of iron from a series of five ferritic steels of varying chromium content and also the associated solution-rate constants decrease with increasing chromium concentration although the equilibrium solubility of iron is the same in all cases

(ii) the rate of solution of iron into bismuth containing 200 ppm zirconium from one selected steel after pretreatment with bismuth–zirconium is reduced and so is the apparent equilibrium solubility of the iron. However, in these cases the solution-rate constant remains virtually unchanged.

Although the bismuth in all cases was analysed for chromium and nickel the amounts found were so low that it is impossible to draw any conclusions about the solution of these elements other than to say that no marked preferential removal occurs over the time for which the experiments were carried out.

It is proposed that (i) above can only be satisfactorily explained by assuming that the factor controlling the rate of solution is the step involving the passage of atoms from the solid into the liquid. The observed changes in the rates of solution and solution-rate constants are then due to changes introduced in or at the surface of the solid by the presence of chromium.

The most probable explanation of the results summarized in (ii) appears to be that the presence of zirconium in the bismuth decreases the solubility of iron in the liquid metal. However, it is also possible that a film of iron–zirconium compound may be formed on the steel surface during pretreatments. This might then decrease the concentration of iron in the liquid phase necessary to reach equilibrium with this solid surface. Such a layer would not be permanent but would be ultimately converted into the zirconium nitride film reported by other workers.

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Surface effects occurring during the heating and cooling of plain carbon steels

M. J. Olney, Ph.D., and G. C. Smith, M.A.

SYNOPSIS

When polished specimens of plain carbon steels are heated and cooled in inert atmospheres it is found that the structure of the surface layers is no longer representative of the interior structure of the specimens. This paper describes an investigation into the nature and causes of these differences in structure. It is concluded that the differences are caused by the fact that the free surface acts as a grain boundary on cooling, thus allowing the nucleation of pro-eutectoid constituents at the surface. Ferrite is nucleated at the surface of hypo-eutectoid steels, and graphite (or in certain circumstances, cementite) at the surface of hyper-eutectoid steels. The effects of variables on the formation of graphite has been investigated, and the use of a high-temperature microscope has enabled observations to be made of the formation of surface films of graphite. 1263

THE WORK to be described arose out of an examination of some of the methods available for revealing austenite grain size in steels. One method which appeared to be simple, and yet to have the most general application, was that of thermal etching in vacuum. In this method a previously polished specimen of the steel is heated in the austenite range in vacuum and then examined. The austenite grain boundaries are clearly revealed as furrows on the surface of the specimen. However, it was found that when the surfaces of specimens treated in this way were chemically etched, anomalous results were obtained and these led to the present investigation.

The literature on the thermal etching of iron and steel has been reviewed by one of the authors elsewhere.[1] Reference will be made in the present paper only to work which is concerned with surface effects, rather than the thermal etching of steels in general.

MATERIALS

The analyses of materials used are given in Table I. Unless otherwise stated, the elements W, Cu, Mo, V, Ti, Co, Al, Sn, and Pb were present only in insignificant amounts.

APPARATUS AND TECHNIQUES

For experiments involving the use of high vacua, the apparatus consisted of a fused-silica tube, sealed at one end, in which the polished specimens were placed. This tube was sealed by means of black wax into a brass collar connected via flexible metallic tubing to an oil diffusion pump backed by a rotary pump. The system included a full-length McLeod gauge flanked by liquid-air traps in which mercury and other deleterious vapours were condensed.

The silica tube was inserted into a small tube furnace so that the specimen itself occupied the central zone of the furnace. The temperature was measured by means of a chromel/alumel thermocouple placed in the furnace with the hot junction in contact with the evacuated tube.

When an argon or a hydrogen atmosphere was

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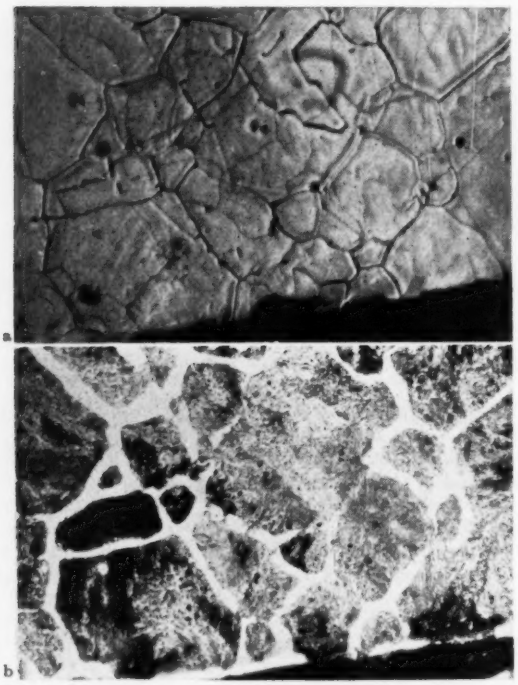
TABLE I Analysis of materials studied

Steel	Composition, %							
	C	Mn	Si	S	P	Ni	Cr	Other elements
BHK 1 (BISRA)	0·25	0·72	0·07	0·020	0·034	0·04	>0·02	Cu 0·08
0·4%C steel	0·41	0·69	0·19	0·029	0·015	nd	nd	...
0·55%C steel	0·58	0·71	0·20	0·028	0·024	nd	nd	...
0·8%C steel	0·81	0·20	0·31	0·013	0·012	0·13	0·06	W 0·10
0·87%C steel	0·87	0·68	0·20	0·023	0·021	0·09	0·05	...
0·9%C steel	0·92	0·24	0·20	0·015	0·018	0·10	0·03	...
1·0%C steel	0·99	0·21	0·30	0·008	0·014	0·08	0·04	...
1·0%C pure alloy	1·00	nd	nd	nd	nd	nd	nd	...
12%Mn steel	1·05	12·30	0·21	0·012	nd	nd	nd	...
1·1%C steel*	1·10	0·20	0·30	0·020	0·020	0·10	0·10	...
1·15%C steel	1·15	0·33	0·18	0·032	0·026	0·13	0·05	Cu 0·11
1·2%C steel	1·17	0·12	0·17	0·020	0·021	0·02	0·04	...
1·5%C steel	1·50	0·27	0·24	0·015	0·023	0·05	0·05	...

* Nominal composition nd = not determined



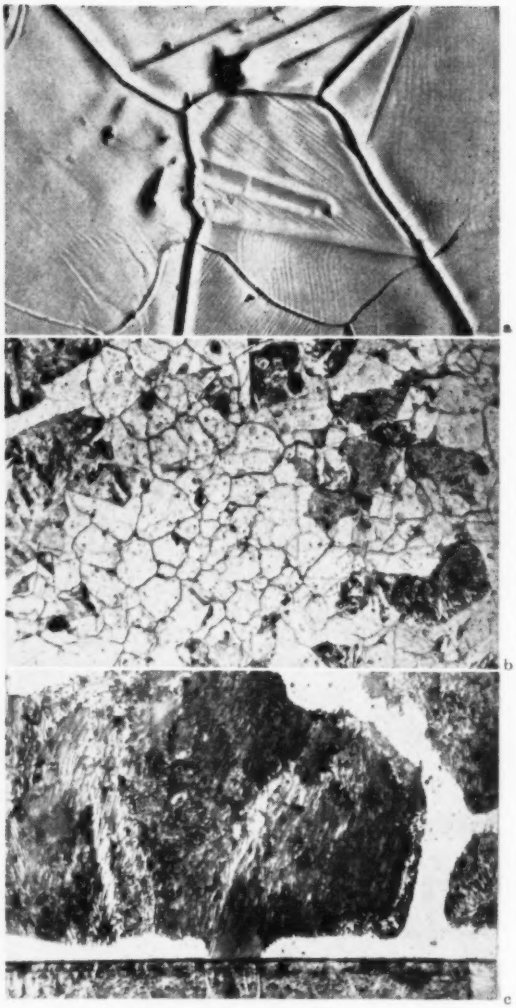
(*a*) Thermal etch, oblique illumination × 250
(*b*) Surface layer removed, etched 5% picral × 250

1 *0·55%C steel heated 2 h at 1000°C in vacuum*

used, the gases were purified and dried by passage through a purification train set up as follows: cylinder —50% potassium hydroxide solution—concentrated sulphuric acid—magnesium perchlorate—finely divided titanium–aluminium at 650°C—magnesium perchlorate—liquid-air trap—furnace tube—concentrated sulphuric acid—to waste. Steel specimens heated in argon or hydrogen purified as described above were bright and free from discoloration after heat-treatment.

In all the experiments to be described, the specimens were usually cylinders $\frac{5}{16}$ in. dia. and $\frac{1}{4}$ in. long. The polishing procedure consisted of grinding the specimens down to 0000 emery, followed by light grinding on a rotating wheel covered with broadcloth soaked in paraffin wax and charged with 600-mesh carborundum. The final polishing operation was carried out on a Selvyt-covered wheel charged with a paste of magnesia and water. After the initial removal of scratches, the specimens were etched in 5% picral and repolished; this procedure of polishing and etching was carried out three times. The final etch was then polished off, leaving a bright surface.

The study of surface changes also involved the examination of specimens sectioned perpendicularly to particular faces. It was therefore necessary to utilize a method of edge preservation effective at magnifications up to × 1500, and the method recommended by Jenkinson[2] was eventually adopted. This consists of the electro-deposition of iron from a chloride bath at 85° C at a current density of 0·011 A/cm². Only thin deposits were obtained even after several hours, and it was found advisable to back up



(*a*) Thermal etch, oblique illumination × 1500
(*b*) Etched 5% picral over thermal etch × 100
(*c*) Sectioned perpendicularly to surface, etched 5% picral × 750

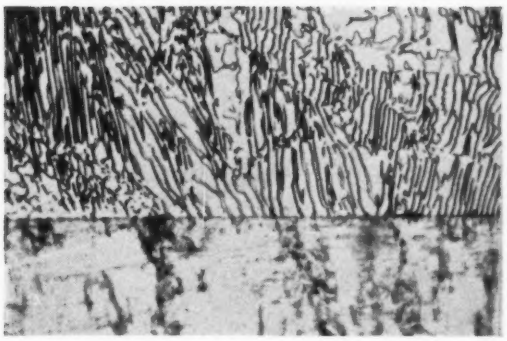
2 *0·55%C steel heated 2 h in vacuum*

the iron deposit with a heavy coating of nickel put on overnight from an acid bath.

EXPERIMENTAL RESULTS

Examination of previously heated and cooled specimens

The initial experiments were designed to determine the suitability of thermal etching for revealing austenite grain boundaries in various steels, and to ascertain whether the boundaries thus revealed coincided with the austenite boundaries existing at the temperature of heat-treatment. Accordingly, a specimen of a 0·55% C steel was heated for 2 h at 1000° C, cooled at 10° C/min to 600° C, and subsequently more quickly, in a vacuum better than 5×10^{-5} mm Hg. When cold, scratches were scribed on the specimen surface to assist in the indentification of selected areas and several such areas were photographed at a magnification of × 250. On etching in 5% picral, the structure shown in Fig. 2*b* was obtained.



3 *0·8%C steel heated 1 h in vacuum, etched thermally and illuminated obliquely* × 750

This shows far more ferrite than is normal in a steel of this composition, and a detailed investigation was made of this effect, as described later. It was possible, however, to obtain the normal ferrite–pearlite structure by polishing and etching away some of the surface. To do this the specimen was electropolished in a perchloric–acetic acid bath at a current density of 0·28 A/cm², then lightly etched in 5% picral; these two operations were repeated until the normal structure of ferrite and pearlite was obtained. The selected areas were again located and photographed at × 250. It can be seen from a comparison of Fig.1*a* and *b* that the correspondence between the austenite boundaries as revealed by thermal etching and the underlying ferrite networks is extremely good. Detailed examination of the photomicrographs reveals that some austenite grain boundaries are incompletely outlined by ferrite deposition, which indicates that thermal etching is more suitable than the deposition of ferrite for revealing austenite grain size in steels of this carbon content.

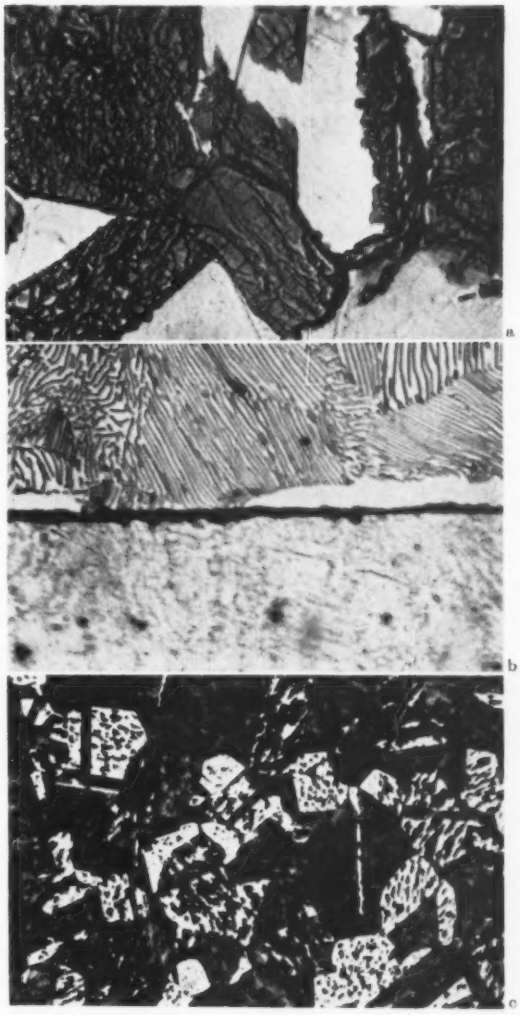
A careful examination of Fig.1*a* reveals a second boundary system accompanying the prominent austenite boundaries. The markings are finer than the austenite boundaries and the two networks appear to be unrelated and to intersect at random.

This fine network is due to ferrite formed at the surface, on cooling, by the decomposition of the austenite, and is seen at high magnification in Fig.2*a*. Figure 2*b* shows the surface of a 0·55% C steel specimen thermally etched for 2 h at 1000° C in vacuum and subsequently etched lightly in 5% picral. The light regions are ferrite and the dark areas are pearlite colonies.

The general distribution and relative abundance of ferrite and pearlite at the surface as shown in Fig.2*b* are not normal for a steel containing 0·55% C in the annealed state in which the pearlite/ferrite ratio should be roughly 2 : 1. Sectioning the specimen showed the presence of thin films of ferrite at many places on the surface as in Fig.2*c*.

There are two possible explanations for the presence of these films, (*a*) the surface layers have been decarburized by the vacuum heat-treatment or (*b*) the free surface has behaved as an austenite grain boundary and on cooling has promoted the nucleation of ferrite in the same manner as the interior boundaries.

The examination of the sectioned specimen indicated that the second explanation was probably the correct one, as the amount of ferrite was found to vary along the surface, whereas decarburization would lead to the formation of a uniform layer of ferrite. In addition, the existence of sharp lines of demarcation between the ferrite films and the pearlite, and the fact that the films were of the right order of thickness to have formed by nucleation were further points in favour of surface nucleation.

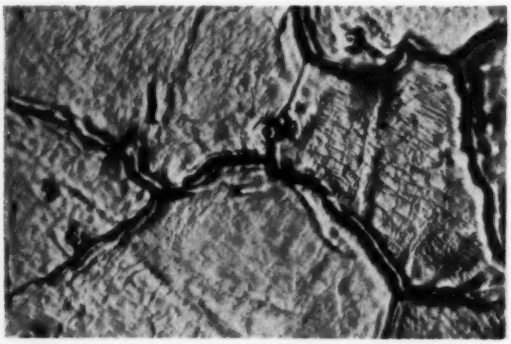


(*a*) Heated 1 h at 1000° C in vacuum, thermal etch, oblique illumination × 500
(*b*) Heated 1 h at 1000° C in vacuum, section perpendicular to surface etched 5% picral × 1000
(*c*) Heated 2 h at 1000° C and cooled rapidly in vacuum, thermal etch × 100

4 *1·15%C steel*

Additional confirmation was obtained as follows:

(1) Specimens of 0·8% C and 0·9% C steels were heated for 2 h at 1000° C and cooled in vacuum. When cold, the specimens were plated, sectioned, and examined microscopically. No ferrite films were visible at the surface in either specimen, although they would have been formed if decarburization had occurred. The absence of ferrite at the surface is



5 *12·3%Mn steel heated 1 h at 1000°C in vacuum and etched thermally* ×100

clearly demonstrated in Fig.3, which is a representative section of the 0·8% C steel specimen.

(2) A specimen of a 0·55% C steel which had been heated for 28 h at 1000° C in vacuum had ferrite films at the surface which were no thicker than the interior boundary network, and in places pearlite had nucleated at the surface. A similar specimen heated rapidly to 1000° C in vacuum and cooled as soon as the temperature was reached also showed ferrite films of similar thickness at the surface. Thus the amount of surface ferrite does not depend upon the duration of annealing as it would if decarburization had occurred.

(3) A specimen of 0·4% C steel heated for 1 h at 1000° C and cooled rapidly in vacuum showed Widmannstäten ferrite penetrating from the free surface into the interior.

(4) A 0·25% C steel heated for 1 h at 1000° C and cooled slowly in vacuum showed no pearlite at the free surface, all pearlite colonies being separated from the surface by a film of ferrite.

(5) Similar experiments with 0·55% C and 0·8% C steels were conducted in atmospheres of purified argon and hydrogen. The results were the same as those obtained when these steels were heated in vacuum, i.e. the 0·55% C specimen showed ferrite at the free surface and the 0·8% C specimen showed only pearlite.

(6) A specimen of a hyper-eutectoid steel should precipitate cementite at the free surface if nucleation of the pro-eutectoid constituent occurred there preferentially, and a specimen of 1·15% C steel was therefore heated for 2 h at 1000° C. and cooled in vacuum. When examined the specimen was found to be partly covered with a grey substance, which was identified as graphite by electron diffraction and X-ray examination (*see* Fig.4*a*). Details of this experiment have been given elsewhere.[3] A similar effect was obtained when the same steel was heated and cooled in argon. The possibility that the graphite was the result of deposition from the gaseous phase was eliminated by control experiments in which specimens of 0·55% C and 1·15% C steels were heated side by side. Only the hyper-eutectoid steel was observed to be covered with graphite after cooling, indicating that the origin of the graphite was internal. A section through the specimen showed the graphite to be associated with ferrite in some regions of the surface, and in others with pearlite, Fig.4*b*.

Influence of different variables upon the formation of graphite

Cooling rate

No graphite was obtained on a specimen of 1·15% C steel quenched into Hg in vacuum from the austenite range, whereas a specimen rapidly cooled at 50° C/min after heating at 1000° C for 2 h showed a considerable amount of graphite on the surface with regions of marked orientation of the graphite nuclei. This is shown in Fig.4*c*.

Carbon content

Experiments with plain carbon steels ranging from 0·87% C to 1·5% C showed that graphitization at a free surface after vacuum heat-treatment was a general effect. The amount of graphite was found to be greater the larger the amount of carbon in excess of the eutectoid content (0·80%) up to a maximum of about 90% surface coverage with 1·5% C. The amount of graphite formed on any particular steel was found to be independent of the time of heat-treatment in the austenite region and of the temperature in the austenite range to which it was heated.

Residual elements

The influence on graphitization of the absence of additional elements normally found in plain carbon steels (Si, Mn, S, and P) was determined by heating a specimen of a pure iron–carbon alloy containing 1·0% C in vacuum for 2 h. After cooling, graphite was observed on the surface indicating that its formation on plain carbon steels was not due to the presence of additional elements.

Heating temperature

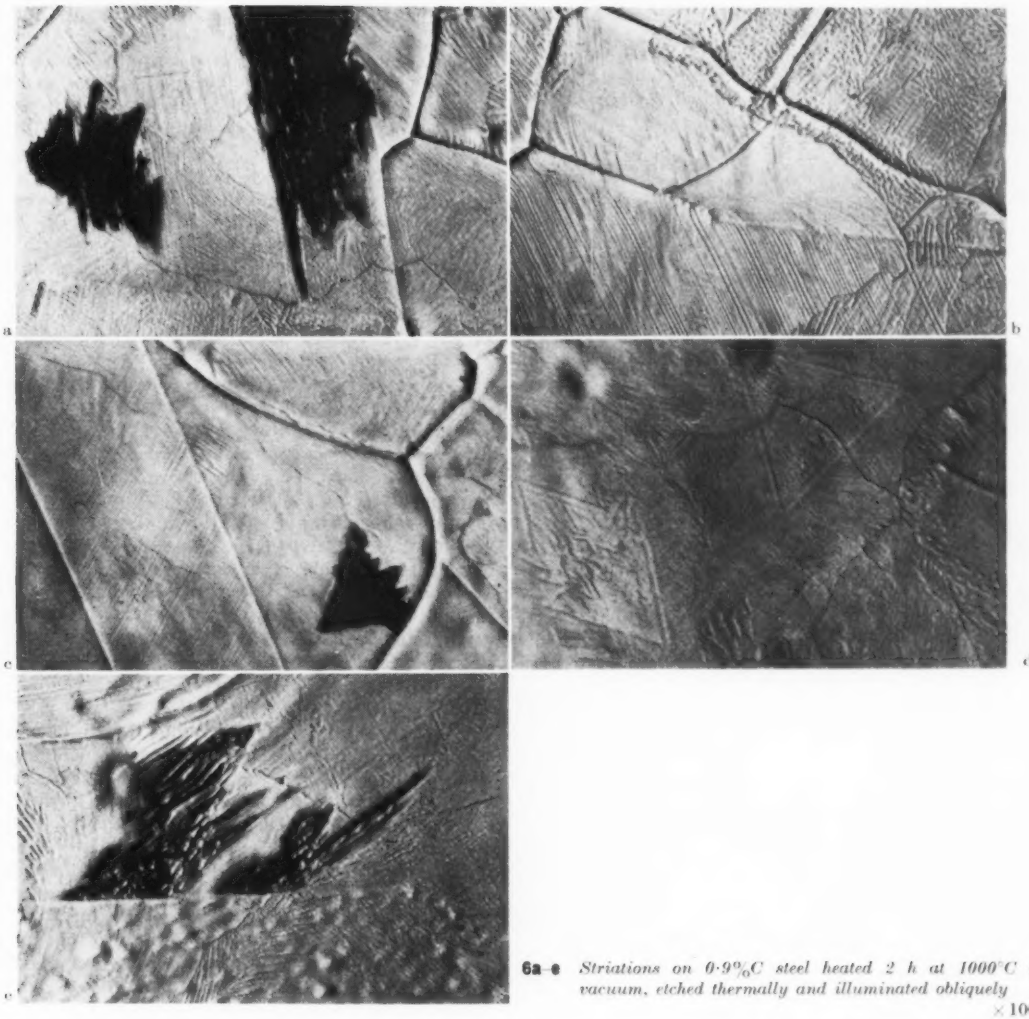
The effect of heating the 1·15% C steel to temperatures below that at which it was rendered fully austenitic was determined by heating two specimens for 1 h in vacuum, one at 795° C and the other at 675° C. After cooling, the first specimen showed a small amount of graphite, the second none at all. This indicates that graphitization occurs only when austenite has been present in the steel during the heat-treatment.

Surface preparation

A specimen of 1·2% C steel was ground on emery papers to 0000 and then electropolished. After heating for 1 h at 1000° C in vacuum, this specimen was observed to be coated with graphite in the same way as specimens which had been mechanically polished.

Alloying elements

The effect of the presence of an element with an affinity for carbon was examined by heating a specimen of Hadfield's Mn steel containing 12·3% Mn and 1·05% C for 1 h at 1000° C in vacuum, and then cooling slowly. A clear thermal etch with no trace of graphite was obtained, but the surface exhibited a peculiar roughness illustrated in Fig.5. It was thought that this might be due to the presence of a carbide film at the surface, and plating and sectioning of the specimen showed such a film, in addition to an interior carbide network surrounding the grains of austenite.



6a–e *Striations on 0·9%C steel heated 2 h at 1000°C in vacuum, etched thermally and illuminated obliquely* ×1000

Reheating

A specimen of 1·2% C steel was heated for 1 h at 1000° C in vacuum and cooled slowly. When cold, reference marks were scribed on the surface and selected areas were photographed. The specimen was then reheated at 1000° C for 1 h, slowly cooled, and the selected areas located and photographed. The distribution of the graphite after reheating was found to bear no relationship to that existing beforehand; the graphite was, however, somewhat finer in texture and more extensive.

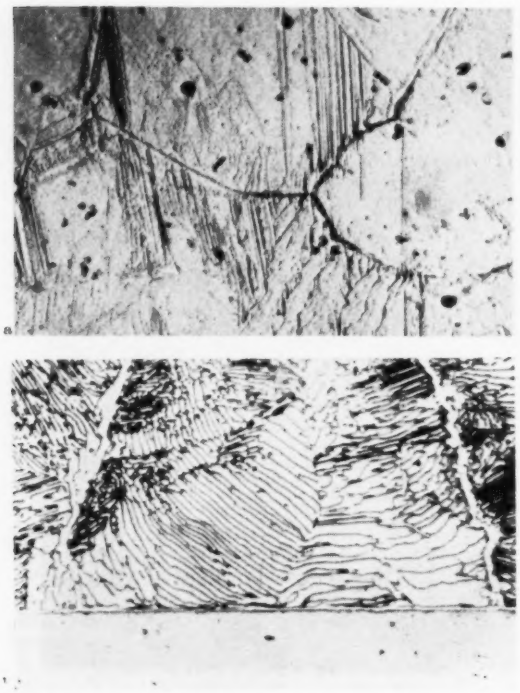
Striations

On steels containing about 0·85%–1·1% C heated and cooled *in vacua*, systems of striations were frequently observed at high magnifications: these can be seen in Figs.6*a* and *b*. The striations change direction or terminate at austenite grain boundaries and twin boundaries, and in regions where graphite has formed the graphite zones are elongated in the direction of the striations, as shown in Fig.6*a*. Another feature frequently associated with the striations is the occurrence of triangular markings, sometimes covered with graphite, as in Fig.6*c*, and at other times not covered, as in Fig.6*d*.

In an attempt to determine the crystallographic orientation of these striations, some specimens were prepared which had two mutually perpendicular faces polished, and the sharp edge between them preserved. These specimens were heat-treated in vacuum in the usual manner, and at points along the edge adjacent areas at right angles to each other were photographed. Examination of a number of such photographs enabled the orientations of certain austenite grains to be determined from the knowledge that the austenite twin boundaries show the positions of (111) planes. This enabled a tentative deduction to be made that the striations are traces of low index planes which are probably (111) planes. The graphite formation can apparently occur with greatest ease on these planes.

Surface orientation

The formation of graphite is sensitive to the orientation



(*a*) Thermal etch, oblique illumination ×500
(*b*) Section perpendicular to surface etched 5% picral ×1000

7 *1·1%C steel heated 2 h at 1075°C in hydrogen*

of the free surface of the austenite from which it forms, as the graphite often reveals the twinning of the original austenite grains, as shown in Fig.4*c*. The same effect is also shown in Fig.6*d* and this also illustrates an additional effect. On one part of the original austenite grain of Fig.6*e* circular surface relief markings persisting from the initial carbide distribution are still present, whilst the other part of the grain surface is quite smooth, except for some fine striations. A straight twin boundary separates the two parts of the grain. It will be seen that the graphite has started to grow along the striations on the smooth part of the grain, but that no growth has occurred on the rough part, and that the cessation of growth at the twin interface is quite abrupt. This indicates that the formation and growth of the graphite is markedly dependent upon the austenite grain orientation and that the removal of surface roughness of the austenite grain resulting from the initial structure is also orientation dependent. Further evidence on these points is presented later in the section on high-temperature observations.

Atmosphere

The behaviour of hyper-eutectoid steels heated and cooled in purified and dried hydrogen is significantly different from their behaviour in vacuum or argon. Figure 7*a* shows the appearance of the surface of a specimen of 1·15% C steel after heating for 1 h at 1000° C and cooling in hydrogen; no graphite has formed, but needle-like markings are present. When the thermally etched surface was etched electrolytically in alkaline sodium picrate, it was found to be half covered with a dark-etching constituent. This indicated the presence of cementite at the free surface, and confirmation of this was obtained when the specimen was plated and sectioned. Figure 7*b* shows the occurrence at the surface of a thin film continuous with the intergranular film. That this was cementite was again shown when it appeared black after etching in alkaline sodium picrate. When the surface film was examined by reflection in an electron-diffraction camera, a strong diffraction pattern with spacings agreeing very closely with the published values for cementite was obtained.

These observations indicate that hydrogen can act as a cementite stabilizer, and so prevent the formation of graphite at the free surface. The surface is still active, however, in promoting the nucleation of the pro-eutectoid constituent.

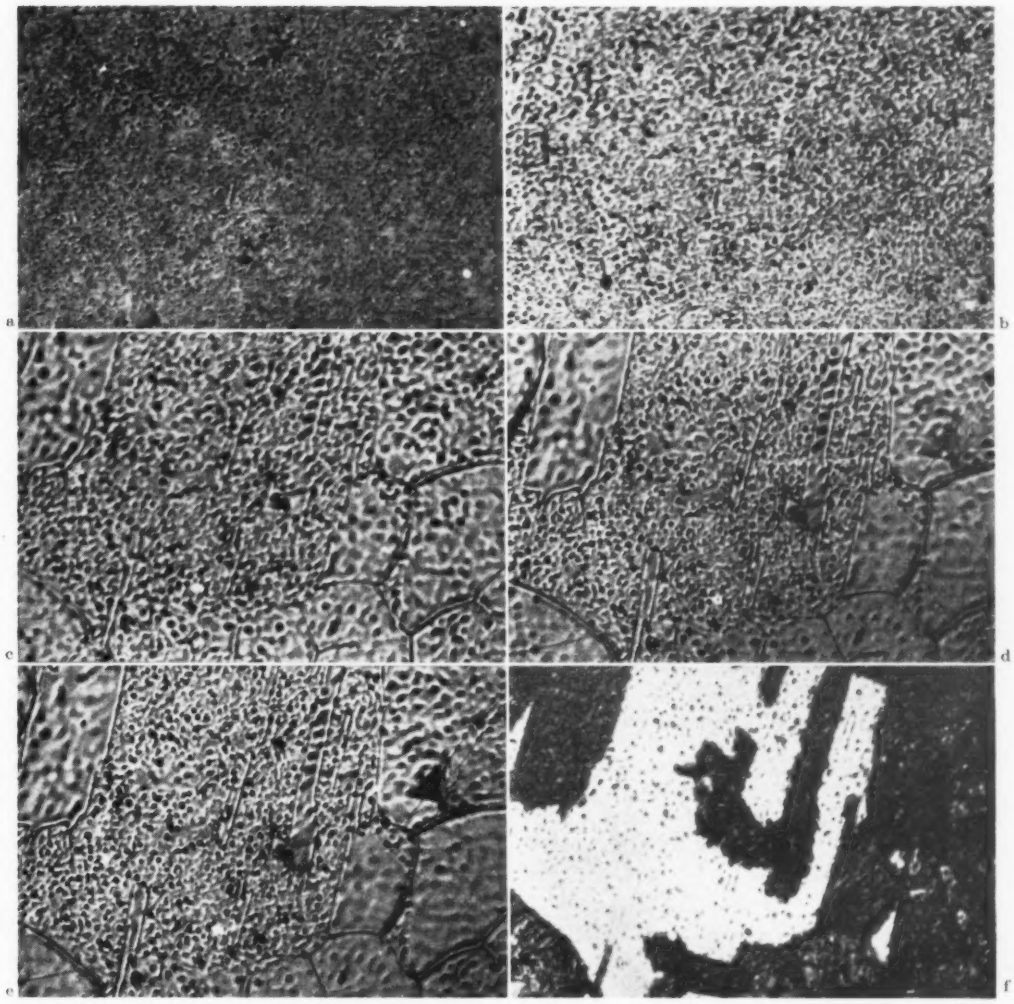
The stability of cementite (in hydrogen) with increased carbon content was tested by heating a specimen of 1·5% C steel at 1075° C for 1 h, followed by slow cooling in hydrogen. Some graphite flakes, frequently associated with the cementite needles, were observed on the free surface. A similar specimen rapidly cooled from 1075° C in hydrogen showed no graphite at the free surface, needles and plates of cementite occurring as on the slower-cooled specimen. It appears, therefore, that rapid cooling in hydrogen of high-carbon steels can suppress graphite formation at the surface, but that the formation of cementite is not affected.

High-temperature observations

Experiments using the technique of direct microscopic examination of polished but un-etched specimens at elevated temperatures have provided additional information about the formation of graphite. The bi-spherical reflecting objective used in these experiments has been described by Dewhirst and Olney[4] and the same paper also contains a description of the vacuum furnace used for heating the specimens. Some preliminary results obtained with this apparatus concerning the formation of graphite during the cooling of a 1·2% C steel *in vacuo* have been described by the present authors.[5] More detailed observations have now been made covering a number of different aspects of graphite formation.

1·17% C steel initially in spheroidized condition

At 666° C (Fig.8*a*) a distinct relief effect was observed owing to the carbide particles, and at 845° C (Fig.8*b*) faint grain boundaries of austenite appeared. On holding at 945° C (Fig.8*c*) the relief effect partly disappeared from some grains and parts of grains, but was quite persistent on others. On cooling a small triangular marking with a little graphite appeared at 839° C (Fig.8*d*) and this became covered with graphite at 786° C (Fig.8*e*). With further lowering of the temperature more nuclei appeared and grew, several having a triangular initial shape. It was observed that, in general, the graphite grew only on those grains and parts of grains from which the original surface relief effect due to the carbide particles had been more or less removed during the heating in the austenite range. Some rough regions of the surface became covered with graphite eventually, but this did not take place until the later stages of growth. Figure 8*f* shows the amount of graphite present at 663° C; no further growth occurred on cooling to room



(*a*) 666° C (*b*) 845° C (*c*) 945° C (*d*) 839° C (*e*) 786° C (*f*) 663° C

8 *1·17%C steel initially in spheroidized condition at different temperatures* ×350

temperature. This observation points to an orientation effect as a result of which those grain surfaces having orientations favourable for the elimination of surface relief are also favourably orientated for the formation of graphite (compare Fig.6*c*).

Effect of reheating and cooling

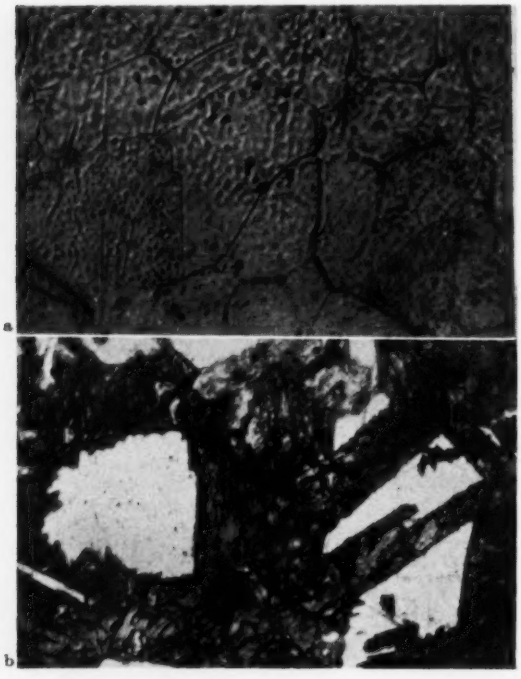
The above specimen was then reheated, and solution of the graphite began at 798° C. This proceeded further with increasing temperature and after 10 min at 944° C (Fig.9*a*) the graphite had been taken completely into solution and new austenite grain boundaries had begun to appear. The new system of boundaries was quite different from the original system, and some regions of the surface which previously had remained rough now became smooth, presumably owing to a different surface orientation of the new grains. The reverse effect was also observed. On cooling, graphite formation occurred as in the previous experiment, the final pattern bearing no resemblance however to that obtained after the first cooling. Figure 9*b*, taken at 691° C illustrates this.

1·17% C steel initially in pearlitic condition

This specimen showed a sequence of changes similar to those of the spheroidized material. One difference, however, was that the roughening of regions of the surface noticed with the spheroidized steel was not so marked in the case of the pearlitic material. On cooling, graphite formation took place in a similar manner.

Isothermal formation after initial nucleation

A pearlitic specimen of 1·17% C steel was austenitized for 30 min at 950° C and then cooled slowly. Graphite nuclei appeared at 774° C and more at 760° C (Fig.10*a*). The specimen was then held at 745° C (Fig.10*b*) for 30 min when graphite continued to form, particularly on the smoother regions of the surface (Fig.10*c*). On subsequent cooling very little



(*a*) 944° C (*b*) 691° C

9 *The same specimen as in Fig. 8 reheated and cooled* ×350

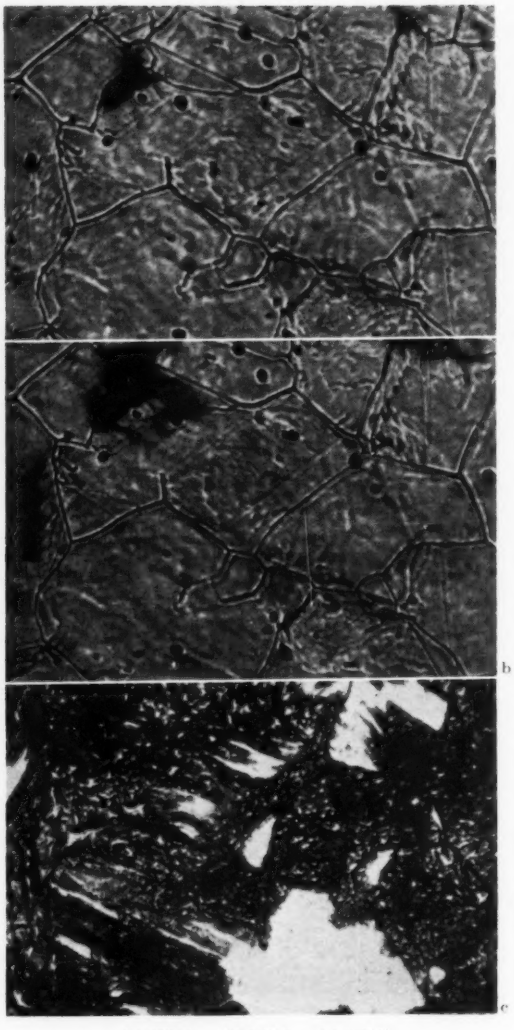
further graphite formation took place. This isothermal formation indicates that the graphite begins to form only when a considerable degree of supersaturation exists, and that there may thus be considerable difficulty in initiating a nucleus.

Supercooling

In a further experiment a specimen of an initially pearlitic steel was held for 30 min at 950° C and then cooled to 840° C and held in order to promote the formation of graphite. The temperature of 840° C was below the temperature at which austenite should start to decompose according to the equilibrium diagram, but was considerably higher than that at which graphite had been observed to form in the previous experiments. Holding for 1 h promoted no graphite formation and further isothermal treatments for 15 min at 10° C intervals down to 780° C were also unsuccessful. No graphite was observed to form until 743° C, at which temperature it grew isothermally.

Intermediate reheating

After austenitizing at 950° C for 30 min a 0·99% C steel was cooled until graphite just started to form at 594° C (Fig.11*a*). Although the temperature was raised immediately, some growth of graphite occurred at first, but at higher temperatures this went into solution, and at 792° C, (Fig.11*b*) complete solution was achieved. On cooling again graphite formed at the same place as initially, but at a higher temperature, (684° C) and on reheating this disappeared by 779° C. Cooling again produced a nucleus at 682° C, and this grew further with lowering of the temperature (Fig.11*c*). This experiment shows that graphite can



(*a*) 760° C (*b*) 745° C (*c*) 746° C

10 *1·17%C steel at different temperatures and times* ×350

be readily dissolved on reheating, but that when re-deposition occurs the initial nucleus can appear in the same position as formerly, but at a somewhat higher temperature.

Isothermal holding on reheating

An experiment in which a specimen covered with graphite was reheated and held isothermally at gradually increasing temperatures, showed that solution began at about 766° C and ended at 863° C.

DISCUSSION

Previous investigators have drawn attention to the fact that a free surface is not necessarily representative of the internal structure of an alloy. The first to do so was Hanemann,[6] who pointed out that a surface untouched by other crystals, i.e. a free surface, would become covered with a segregate, in an alloy undergoing a transformation on cooling, in the same way as the contact surface between two interior grains.

Etching would attack only the surface layer of the segregate and the structure of the alloy would appear homogeneous rather than heterogeneous. Hanemann presented no experimental evidence in support of his hypothesis.

Sauerwald, Schultze, and Jackwirth[7] observed that hypo-eutectoid steels slowly cooled after vacuum annealing did not reveal the true structure when chemically etched until the surface layers had been ground away. They considered that Hanemann's explanation was correct and that ferrite formed in plates parallel to the free surface, thus masking the underlying structure.

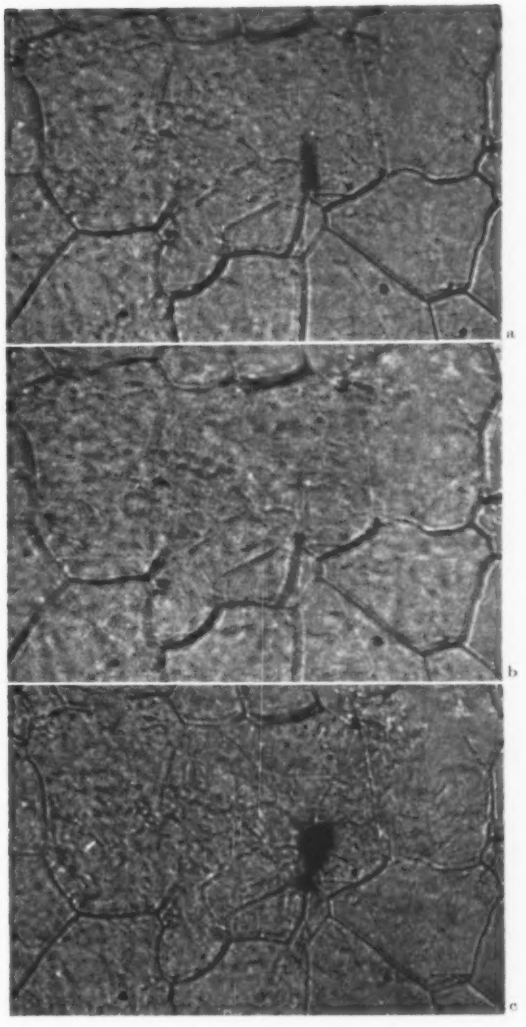
Apart from Hanemann, Howe appears to be the only other investigator who considered seriously the possibility that a pro-eutectoid constituent could form at an exterior surface. The first mention of Howe's suggestion appeared in the discussion of a paper by Burgess, Crowe, and Rawdon.[8] In this paper, Rawdon reported that a hole drilled in a cylinder of 0·4% C steel, which was subsequently heated in vacuum, became coated with a thin layer of ferrite after heat-treatment. Rawdon attributed this to decarburization, but Howe in discussion stated that in his opinion the layer of ferrite was formed on cooling by an expulsion to the surface of the austenite grains. He also described further experiments which involved the use of both hypo- and hyper-eutectoid steels, the results of these experiments being in accord with the explanation given above. Howe later gave further consideration to the idea of the expulsion of pro-eutectoid constituents to exterior surfaces. These results of Howe's are consistent with the present findings if the word 'nucleation' is substituted for what Howe termed 'expulsion'.

Further experimental work in this field has been reported by Rawdon and Scott,[10] and by Hemingway and Ensminger.[11] Their results can in general be explained in terms of a surface-nucleation theory, but the theories put forward by them to explain their own results are inadequate to explain the results obtained in the present work.

The present results show that the free surfaces of austenite grains can nucleate pro-eutectoid constituents on cooling, in the same way as do interior boundaries. The behaviour of hyper-eutectoid steels *in vacua* or argon is exceptional in that graphite forms at the free surface whilst the normal cementite network occurs at the interior grain surfaces.

It appears that graphite formation is subject to the limitations of the iron–carbon equilibrium diagram in that it only takes place on hyper-eutectoid steels, and the quantity formed is roughly proportional to the amount of carbon in excess of the eutectoid content.

As the stable iron–carbon system is that consisting of iron and graphite, it is possible that a free surface of a hyper-eutectoid steel on cooling from the austenite range behaves in accordance with the iron–graphite equilibrium diagram while interior boundaries conform to the conditions imposed by the metastable iron–cementite diagram. The absence of neighbouring atoms at the free surface may facilitate the nucleation and growth of graphite, a more voluminous constituent than cementite. An initial difficulty of nucleation of graphite, compared with cementite, may be the reason why graphite does not usually form inside high-carbon steels.



(*a*) 594° C (*b*) 792° C (*c*) 661° C

11 *0·99% C steel, initially pearlitic, at different temperatures and times* ×350

The fine striations often observed on austenite grains, particularly in the case of steels of 0·9%–1·0% C appear to be the traces of (111) planes. The striations probably form as a result of minimum surface energy considerations, as although the total surface area will increase, the total surface energy can decrease if the planes exposed are of low surface energy. Recent work by Moore[12] on silver has shown that striations will occur only when (100) or (111) planes make angles with the surface of less than certain critical values.

The frequent appearance of hexagonal markings on the graphite indicates that it probably forms with the basal planes of the hexagonal lattice parallel to the surface. The arrangement of atoms in the basal plane of the graphite lattice is hexagonal with the a dimension equal to 2·456 Å and the c dimension 6·694 Å for α-graphite. It is known that the a dimension does not alter appreciably with temperature up to 800° C.

Austenite (fcc) has a cell dimension of 3·64 Å at 910° C. This gives an interatomic distance of 2·57 Å, and the arrangement of interstitial carbon atoms on (111) planes leads to the formation of hexagons whose unit cell dimensions is 2·57 Å, as compared with 2·456 Å, the actual unit cell dimension of α-graphite. No other planes give rise to simple hexagonal arrangements of atoms, and this may be the reason why graphite appears to form most readily on surfaces which have (111) planes parallel, or very nearly parallel, to the surface.

Graphite formation occurs most readily on grain surfaces from which traces of the original structure have been most completely eliminated. It seems, therefore, that the mechanism responsible for the smoothing of surfaces, i.e. migration of ions over the surface, operates most effectively when (111) planes are parallel, or almost parallel, to the surface.

ACKNOWLEDGMENTS

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Thermal considerations in oil quenching

G. Stolz, Jr, V. Paschkis, C. F. Bonilla, and G. Acevedo

SYNOPSIS

Quenching experiments were performed in three different quenching oils, and the pertinent thermal relations, boundary conductance v. *surface temperature, are reported. The effect of oil temperature, immersion depth, and position on the surface of the sample was examined.*

A wide range of factors tested is condensed into a few graphs from which related thermal quantities (e.g. temperature/time curves) can be obtained.

The physical phenomena occurring in the quenchant which affect the cooling behaviour are discussed. 1602

INTRODUCTION

Purpose

THE HARDNESS achieved at any point of a quenched piece depends on the temperature/time relation at this point. Yet most quenching research bypasses the exploration of these temperature/time relations and attempts to correlate hardness observations and possibly metallurgical structure with relatively few constituents of the thermal picture such as nature of the quenchant, velocity, size of the piece, etc. Despite all the valuable work done, quenching still remains an 'art'. In the present study the major objective was the determination of the one significant thermal quantity which completely describes the behaviour of the quenchant, the boundary conductance, and the influence on boundary conductance of significant variables. It is hoped that the present approach will reduce the element of art and contribute further toward a scientific approach to quenching.

Previous work

Four of the principal references in the field deserve discussion. The Jominy test[1] serves to compare the hardenability of steels by exposing a standard shape to a standard spray quench and measuring the surface hardness distribution. While the test has become standard and is of great use in practical heat treating, it is doubtful that further exploration in this direction can contribute to a more fundamental analysis of the quenching process.

Grossman and Asimow's[2] concept of severity of quench, H (which was also called heat transfer equivalent), recognizes in principle the need of separating hardenability from heat transfer. But while H is conceptually defined as a thermal quantity, it is determined from hardness measurements. Thus H becomes more an empirical correlating factor which works well under restricted conditions, but fails when applied where the assumptions are not at least approximately satisfied. The most important restrictive condition which, unfortunately, is satisfied infrequently is constancy of boundary conductance over

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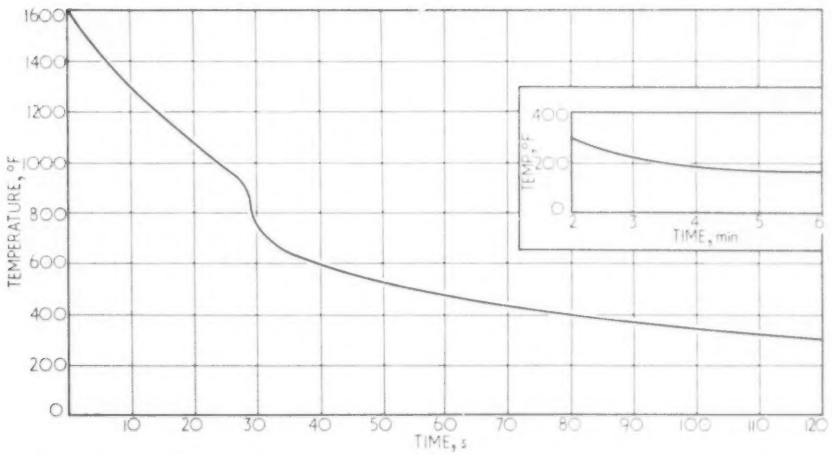


1 *Typical cooling curve for slow oil under reference conditions*

a range of temperatures, surface positions, and specimen sizes. Thus attempts to apply Grossman's H without regard to its limitations cannot prove generally useful.

Finally, reference should be made to the work at the Kaiser Wilhelm Institut (now Max Planck Institut) für Eisenforschung[3–5] in which silver spheres were quenched to compare cooling rates, which in part suggested the approach in the present study.

The methods of the Kaiser Wilhelm Institut have been adopted by several other investigators. The work of Russell[6] may be of interest, although the similarity between Russell's work and that reported in this paper is only in the experimental method. The concepts employed (e.g. boundary conductance) and the end results are different. Further the status of current knowledge of boiling phenomena[7,8] requires extensive revision of Russell's physical interpretation. In view of the differences in approach further reference to earlier papers does not appear necessary.

Investigators at the Kaiser Wilhelm Institut worked necessarily with samples small enough to be considered isothermal. But it is known that cooling rates are a function of position, and also shape and size of the cooling object, particularly if the object is small. Therefore, the specific results reported by those authors based on such small samples cannot easily be generalized. Thus the present work was started in the hope of leading to a quantitative understanding of the cooling process precise enough for the eventual prediction of cooling rates in an object of any size or shape in any quenching medium, provided relatively few key physical constants are known.

The investigation of Yoshida *et al.*[18,19,20] was similar to the present one. Seven liquids were tested, among them 'mobile oil', 'spindle oil', and mixtures of the two. Specimens were carbon steel cylinders, 1·5–2·5 cm dia., 12–15 cm long, with the axis vertical. From a single thermocouple at the surface the boundary conductance was determined. Their method of calculation is questionable. Qualitatively, their results and those of this paper check both with regard to the boundary conductance temperature curve and to the small influence of oil temperature.

THERMAL DESCRIPTION OF QUENCHING PROCESS

The important thermal factors in quenching can be classed in two categories; one pertains to the quenchant; its behaviour is characterized by the boundary conductance, h (Btu/hft²°F), which is defined as the rate of heat transfer per unit area per unit temperature difference. Many variables influence the boundary conductance, among them the quenchant, its temperature, amount of agitation, geometry of specimen and container, etc., but most important, it is substantially independent of the material of the quenched specimen.

The second thermal category pertains to the solid body, specified by its size, shape, and material. The material in turn is described by thermal properties such as thermal conductivity, specific heat, density, heat, and range of transformation. Most of these factors are well understood, though for many solids numerical values are not known with desirable accuracy.

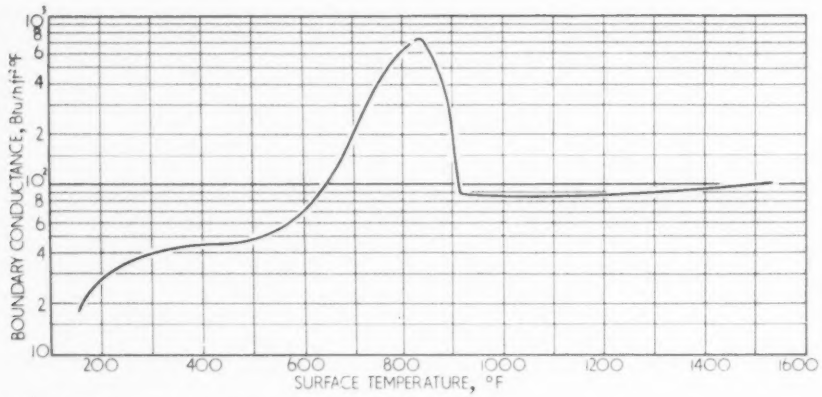
These two groups, boundary conductance and thermal properties, when known, are sufficient to determine for a quenched piece any desired temperature/time/space relations, such as cooling curves, cooling rates, temperature profiles, etc. Thus the importance of the boundary conductance lies in the inherent generalization of results.

The purpose of the 'co-operative quenching program' at Columbia University, of which this paper is a progress report, is the exploration of the boundary conductance.

BOUNDARY CONDUCTANCE AND COOLING CURVES

The physical phenomena that occur in the quenchant and affect the course of boundary conductance and in turn cooling curves are perhaps best explained with an example based on an actual experiment.* Figure 1 shows the temperature/time curve measured near the surface of a sample; from this the relation of boundary

* Some of the interpretation provided is based on the authors' observations. In the regions of rapid change, however, views currently held for steady state boiling are summarized, drawing especially upon the high-speed photographs of Westwater.[8]



2 *Typical boundary conductance curve, corresponds to Fig.1*

conductance *v.* surface temperature* shown in Fig.2 was calculated.

From 1600° to 920°F the sample is blanketed by a film of oil vapour through which heat is passing to the surrounding liquid oil, which in turn is removing heat by natural convection. This stage is called film boiling. As the sample cools, the film thickness gradually decreases. Because of the relative insulating effect of the vapour film, the boundary conductance is rather low and changes slowly over a narrow range, e.g. in this experiment from 100 to 88 Btu/h ft² °F. Consequently, the slope of the cooling curve is not steep.

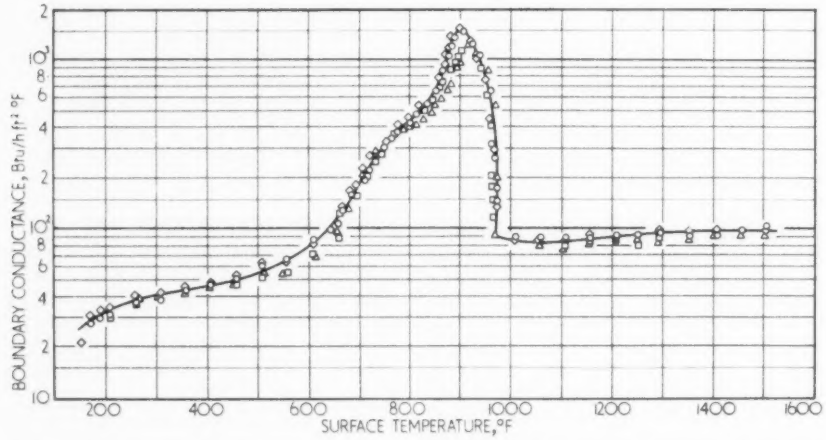
Starting at 920°F transitional boiling is encountered. It is a hydronamically unstable region in which the vapour film fluctuates in apparently random fashion, agitating the surrounding liquid. While the surface temperature is dropping only a few degrees (from 920° to 830°F) the boundary conductance as shown in Fig.2 is increasing very markedly from 88 to 720 Btu/h ft² °F. At about 920°F the slope of the cooling curve changes appreciably and becomes steep.

Nucleate boiling starts at 830°F and is characterized by the rapid formation of many small bubbles promoted by 'nuclei' such as surface irregularities, impurities in the oil, and the like. As the surface cools, the rate of bubble generation decreases, resulting in lower boundary conductance values. At about 650°F, somewhat above the initial boiling point of the oil, boiling ceases. In the nucleate boiling range (830–650°F) the boundary conductance falls from the peak value of 710 to about 100 Btu/h ft² °F. Near 830°F the inflection point corresponding to the maximum boundary conductance may be seen in the cooling curve, after which the cooling rate decreases. Below 650°F further cooling is by natural convection, which may at first be turbulent and ends in laminar flow. Boundary conductance is once more low and changes slowly as does the sample temperature during the rest of the process.

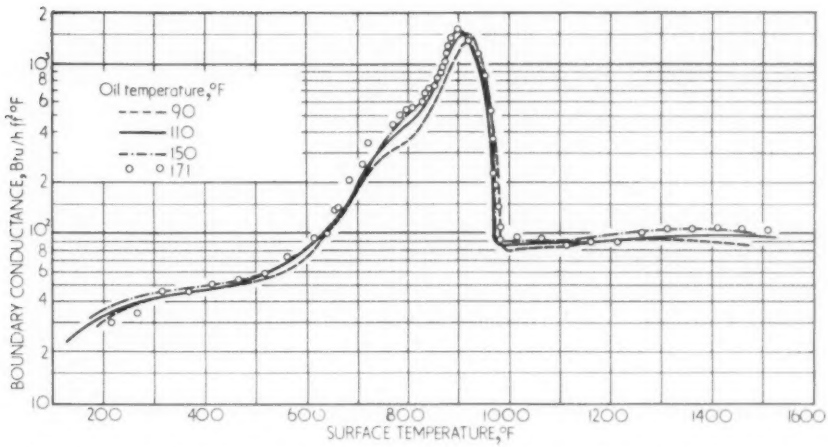
TEST PROCEDURE

The variation of the boundary conductance during a quench is obtained as follows. Temperatures at known positions inside a sample are measured. By mathematical analysis, the surface temperature and rate of heat flow through the surface are determined. The above data define the course of the boundary conduct-

* For clarity this manner of presentation differs from the usual convention. In heat transfer plots of this type the custom is to plot as abscissa the difference between surface temperature and bulk quenchant temperature.



3 *Boundary conductance v. surface temperature for intermediate oil under reference conditions, showing reproducibility of experiments. Four separate runs are indicated by different symbols. The solid line represents the mean*



4 *Boundary conductance v. surface temperature for intermediate oil, showing effect of oil temperature*

ance, which then can be correlated with time, or more meaningfully, with the surface temperature.

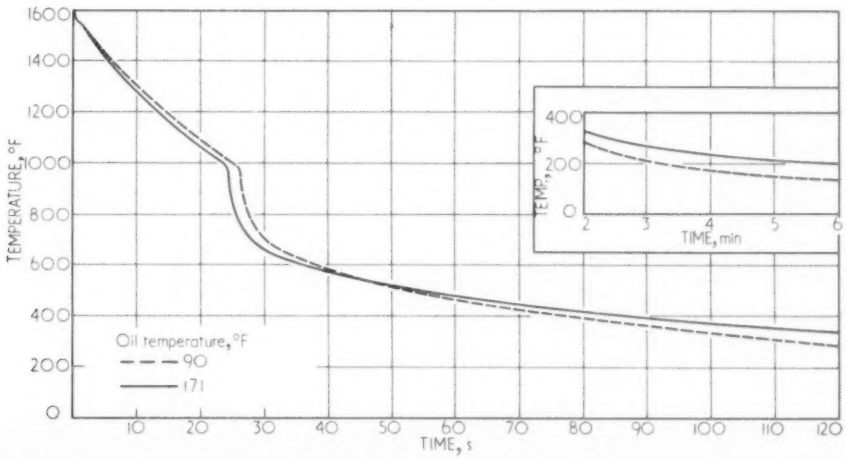
The experimental setup has been described previously[9,10] and is therefore reviewed only briefly. The samples were two silver spheres of 2 in. dia. and an average surface roughness of 140 μin.; they were quenched in three different oils designated as fast, intermediate, and slow. The oils are described in the Appendix. Each sample, supported by a silver tube in turn attached to a dropping mechanism, was heated in a resistance furnace, then dropped into a quench tank. Temperatures were measured by silver/alumel thermocouples with the sample serving as part of the silver leg. Alumel wires of 0·020 in. dia., insulated by alundum tubing, were welded to the bottom of 0·042 in. holes at various locations (five or fewer) in the sphere. Locations are described by their radial distance from the centre and latitude, α, the angular deviation from the vertical; at the 'south pole' α is zero.

During the quench thermocouple emf's were recorded on a Hathaway six-channel oscillograph with mirror galvanometers. One channel served to record the sample position during the drop. The galvanometer deflection/time traces were read out at frequent time intervals with the aid of a special oscillogram reader.[11]

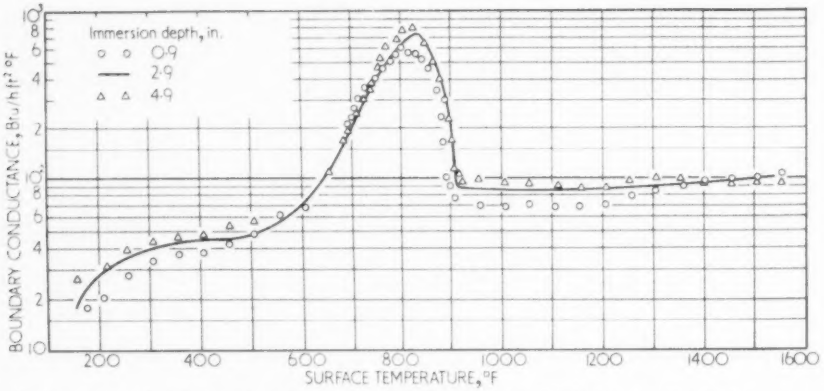
To obtain the boundary conductance values from these interior temperatures, special numerical techniques[12] were developed. Essentially, the measured temperatures are extrapolated to the surface, assuming spherical symmetry. The gradient of the temperature (derivative with respect to radius) and the temperature at the surface are determined. By Fourier's law, heat flux (rate of heat transfer per unit area, Btu/hft²) is obtained and divided by surface temperature difference to yield boundary conductance.

Reference test

Since many factors may affect the boundary conductance, a 'reference test' was selected as comparison standard. In the reference test the quenchant was at 110°F and initially quiescent in a deep 38 in.×31 in. tank. The sample, initially at 1600°F, was dropped vertically into the quenchant at 3 ft/s until the 'north pole' was submerged by 2·5 in. Unless otherwise noted, all the experiments discussed were performed under these conditions.



5 *Cooling curves for intermediate oil corresponding to Fig.4, showing effect of oil temperature*



6 *Boundary conductance v. surface temperature in slow oil at 110°F, showing effect of immersion depth*

EXPERIMENTAL RESULTS

Range of conditions

Earlier tests in aqueous quenching media (demineralized water and caustic soda solutions[9,10]) indicated a large influence of the quenchant temperature and immersion depth. Accordingly the independent factors varied in the present investigation, and their ranges were:

(i) quenchant: slow, intermediate, and fast oil
(ii) quenchant temperature: 90–170°F
(iii) immersion depth: 0·5–5·2 in.
(iv) latitudinal position: 10–85° of arc.

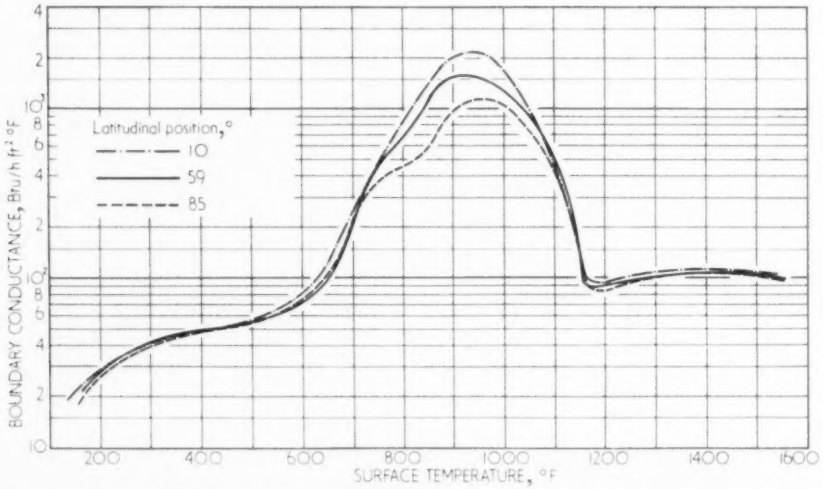
Reproducibility

As shown in Fig.3, presenting boundary conductance *v.* surface temperature, good reproducibility of both experiment and analysis is achieved under most conditions. The agreement among either slow or fast oil quenches is somewhat better than for the intermediate oil. One isolated instance of severe disagreement in the intermediate oil was observed six months after the completion of the experiments; this finding is otherwise unconfirmed. It is not shown in Fig.3.

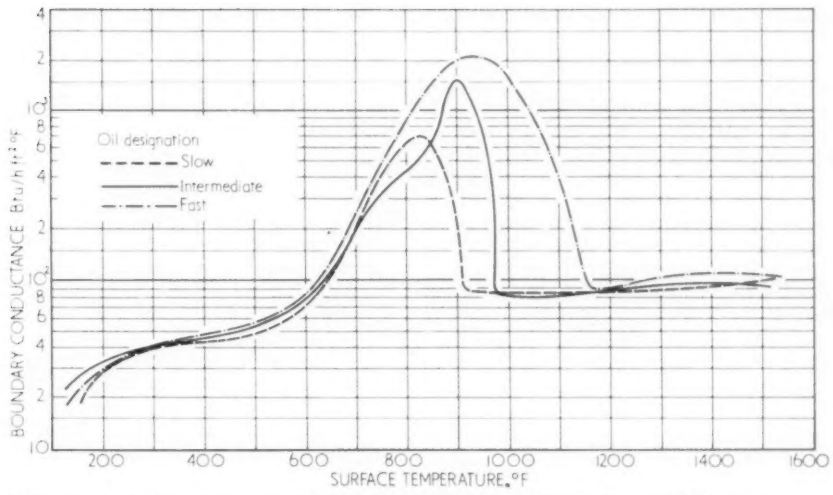
Effect of oil temperature

In the range of oil temperature considered (90–170°F) for each oil all the results coincide when boundary conductance is plotted with surface temperature as abscissa, as shown in Fig.4 for the intermediate oil. This is surprising, since heat transfer data in natural convection and boiling usually correlate well when temperature difference (between surface and liquid bulk) is used as abscissa (*see*, e.g. ref.13).

The explanation of this behaviour would seem to be that with these viscous oils considerable thermal resistance must exist in the liquid phase, between the outer surface of any vapour layer and the bulk of the liquid. In this case, the temperature of the outer surface of the vapour layer (inner surface of the liquid) would be controlled more by the temperature of the quenched surface and the boiling process than by the bulk of the quenchant. Thus the quenching heat transfer would correspond more closely to saturated boiling than to sub-cooled boiling, and the quenchant bulk temperature would not affect the boundary conductance. The above finding does not imply that the cooling curves would be identical, though they do not differ by much, as shown in Fig.5.



7 *Local variations of boundary conductance at different positions on sample surface, fast oil under reference conditions*



8 *Boundary conductance* v. *surface temperature, reference conditions, comparison of three quenching oils*

Differences in hardness with changing oil temperature, say from 90° to 130°F, have been observed elsewhere.[14] This experience may seem difficult to reconcile with the fact that this change in oil temperature results in very little change in cooling curves. By way of explanation it has been suggested[15] that these differences in hardness are governed by the progress of the martensite reaction (occurring at the very end of the cooling curve) which may be very sensitive to the temperature of the oil bath.

Effect of immersion depth

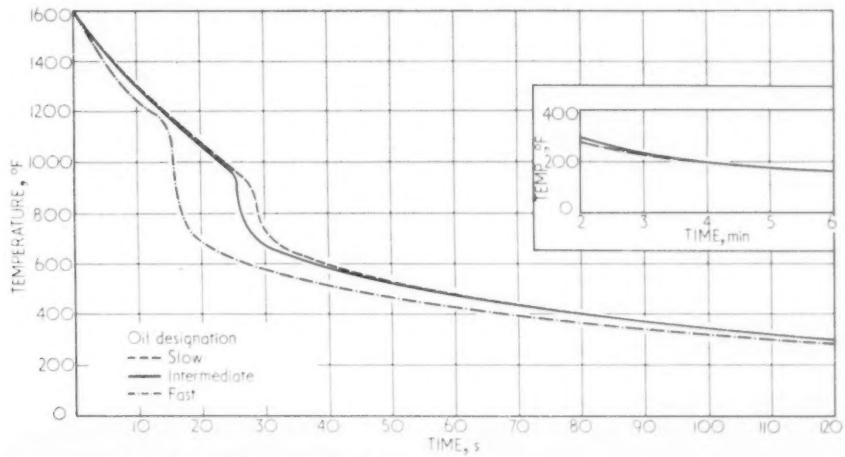
Shallow immersion of less than about one sample diameter in all three oils yielded slower cooling than at depths beyond this limit. For example, quenches at depths of 4·9 and 2·9 in. (measured from the top of the sphere) in the slow oil (Fig.6) yielded no appreciable difference in boundary conductance. But when the depth was decreased to 0·9 in. a considerably lower boundary conductance resulted, with consequent slower cooling.

The hydrostatic head is probably a negligible cause of these differences. However, the proximity of the oil/air interface to the sample constitutes a boundary, in part similar to a solid wall, tending to restrict the circulation of the quenchant. When this free boundary is sufficiently far removed from the sample, no appreciable effect would be expected as the depth is changed. On the other hand, if the free boundary is moved close enough to the sample, the circulation of the oil is impeded. A lower overall boundary conductance would be expected.

On the basis of this explanation one would expect slower cooling whenever some obstacle to free oil circulation is too close to the piece. Such an obstacle could be the oil/air interface, a tank wall or bottom, or another object being quenched at the same time.

Effect of location

Figure 7 demonstrates an appreciable variation of boundary conductance with position on the surface of the sphere. This variation evidently occurs only in the rapid cooling region and would therefore be reflected in cooling curves only for short periods of



9 *Cooling curves corresponding to Fig.8, comparison of three quenching oils*

time, but during such periods large temperature differences at different locations might be expected.

The effect of latitude is negligible in regions of low h when silver samples were used; more significant differences may occur in different materials. The differences at high h may be explained as follows. It has been observed that bubbles form first near the top of the sample, then in about 0·3 s spread around to the bottom. This time lag in bubble formation may be explained by the oil circulation near the sample. In convective flow past a round object turbulence develops first on the downstream side, which in natural convection is at the top of the sample. With more agitation at the top, the vapour layer breaks down more easily there. To some extent the presence of the supporting rod probably also contributes. Such differences could cause significant non-uniformities of hardness and depth of hardness.

Comparison of three quenching oils

Figures 8 and 9 compare the thermal behaviour of the three quenching oils under reference conditions. They show, respectively, boundary conductance and cooling curves.

Between 1600° and 1150°F the boundary conductances and thus the cooling curves of all three oils are similar; over this range all three oils are in the film boiling regime. From 700° to 130°F, which covers the colder region of nucleate boiling and the convective cooling regime, similar conditions are also found with the three oils. In these regions corresponding portions of the temperature/time curves have the same form.

The convective regime has been satisfactorily correlated elsewhere in terms of dimensionless ratios employing physical properties, and this agreement among the oils might have been expected from the similarity of their key physical properties, which are shown in the Appendix.

The main differences between these oils lie in the height and breadth of the boundary conductance curve in the region of rapid cooling where the boundary conductance exceeds 100 Btu/hft² °F. Both the height and breadth are greatest in the fast oil (Fig.8). For the fastest oil the breadth of temperature range of high h is 530°F (from 1150° to 620°F). For the slow oil the breadth is only 280°F. Since the lower temperature limit is the same in all cases, the essential difference lies in the temperature at which stable film boiling is interrupted,* possibly due to a difference in the wetting properties of the oils. The differences in the peak values of h do not seem to play as large a role in cooling speed of these quenchants. However, the study of the boundary conductance evidently yields a quantitative comparison of the effectiveness of quenching media.

CONCLUSIONS

(1) A single relation between boundary conductance and surface temperature is valid for a wide range of oil bulk temperatures and a range of immersion depths.

(2) If the three oils may be considered as characteristic of slow, medium, and fast quenching oils in general, one can state that the difference in quenching behaviour of oils lies in the temperature at which the stable vapour film breaks down.

(3) All three oils behave almost identically in part of the film boiling range and in the natural convection range.

(4) Oil temperature has only a negligible influence on the boundary conductance. This is in contrast to aqueous quenching media.

(5) The depth of immersion of an object in the oil may be limited by the depth of the tank. Shallow immersion reduces the cooling rate noticeably, but beyond a certain critical value further increase of depth of immersion has only a minor influence on the cooling behaviour. For large objects, therefore, even the top of the object should be immersed deeper than this critical depth; otherwise irregular quenching will result.

(6) Boundary conductance values can be non-uniform over the surface of the spheres. The differences are most marked at high values of boundary conductance. Further study of this phenomenon is necessary, both for a fuller understanding than indicated in this paper and to see the practical implications of non-uniformity of quenching.

(7) Boundary conductance values as presented in this paper can be used to predict cooling curves in objects of size and material different from the experimental samples. Such predictions are contained for example in a paper presented by one of the authors.[16] Experiments in progress will serve to verify the validity of such predictions.

ACKNOWLEDGMENT

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APPENDIX

DESCRIPTION OF THE QUENCHING OILS

Three oils were donated by Gulf Research and Development Corporation. They are designated as slow, intermediate, and fast. These designations were chosen rather than brand names, and pertinent properties are reported. The slow quenching oil is a commonly used all-purpose paraffinic-type oil. The intermediate oil is covered by US Patent 1535379 issued 28 April 1925; it was made up from nine parts of slow oil and one part of an additive.

The three thermal properties, thermal conductivity, specific heat, and latent heat of vaporization were not determined, but can be calculated from known properties according to accepted empirical equations.[17]

The formulae used are as follows:

$$K = (0{\cdot}813/d)\,[1 - 0{\cdot}0003\,(t - 32)]$$
$$C = (1/\sqrt{d})\,(0{\cdot}388 + 0{\cdot}00045t)$$
$$L = (1/d)\,(110{\cdot}9 - 0{\cdot}09t)$$

where K = thermal conductivity, Btu/h ft² °F/in.
C = specific heat, Btu/lb °F
L = latent heat of vaporization, Btu/lb
d = specific gravity at 60–60°F
t = temperature, °F

* Russell[6] called a nearby point, picked by inspection of cooling curves, the 'characteristic temperature'.

Typical values of the thermal properties calculated from the above formulae are shown in Table II.

TABLE I Properties of quenching oils*

Property	Slow oil	Intermediate oil	Fast oil	Additive
Gravity, API	27·7	27·0	30·0	28·6 at 141°F
Specific gravity at 60–60°F	0·8888	0·8927	0·8762	0·8838 at 141°F
Viscosity SUS 100°F	103	137·0	92·9	4695
130°F	64·5	78·4	61·6	1616
210°F	39·0	42·0	38·9	225
Pour point, °F	+10	+25	+15	0
Flash point, OC, °F(D92)	360	375	370	>620
Fire point, OC, °F (D92)	410	430	415	...
Carbon residue, % (D189)	0·01	0·14	0·73	2·07
Neutralization value acid no. (D974)	0·01	0·03	0·06	0·14
Saponification no. (D94)	0·1	0·6	0·6	...
n-Pentane insolubles, % (D893)	<0·01	<0·01	<0·03	0·02
Benzene insolubles, % (D893)	<0·01	<0·01	<0·01	<0·01
Initial boiling point, °F	644	680	887	...

* By courtesy of Gulf Research and Development Company, Pittsburgh, Pennsylvania.

Surface tension was not determined, but according to past experience of the producer the approximate value for the three oils is 32 dyn/cm at 88°F.

TABLE II Typical values of thermal properties

Property		Slow oil	Intermediate oil	Fast oil
Thermal conductivity, Btu/hft² °F/in.	100°F	0·896	0·892	0·911
	200	0·867	0·865	0·883
	300	0·841	0·837	0·855
Specific heat, Btu/lb °F	100°F	0·459	0·458	0·463
	200	0·507	0·506	0·511
	300	0·555	0·554	0·559

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A resistometric study of the first stage of tempering in plain carbon steels

H. W. King, B.Sc., Ph.D., and S. G. Glover, B.Sc., Ph.D.

SYNOPSIS

The tempering of seven plain carbon steels ranging in carbon content from 0·19 to 1·5% has been studied at temperatures from 23° to 100°C by measurements of the change of electrical resistivity. Steels containing 1·27%C or above when tempered below 80°C exhibit an initial increase in resistivity before the normal decrease characteristic of all the steels examined. This anomaly is considered to be associated with the precipitation of ε-carbide in coherent form.

The decrease in the resistivity of the 0·19%C steel (2%) is much smaller than that of the other steels (14–30%) and is ascribed to the segregation of carbon atoms in the martensite rather than to the precipitation of carbide. This view is supported by the marked difference between the time dependency of the resistivity change in this steel and that for the steels of higher carbon content. The detection of a resistivity change in a 0·19%C steel is thus not incompatible with the formation of a metastable low-carbon martensite (0·25%) during the first stage of tempering of high-carbon steels.

The activation energy for the first stage of tempering has a unique value for each steel but varies with the initial carbon content of the martensite according to the linear relationship:

Activation energy = 8500 × wt-%C + 18000 cal/mole

This relationship is discussed with reference to the possible diffusion paths of carbon in martensite.

1601

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IN PRECIPITATION PROCESSES, particularly when the decomposing phase is grossly supersaturated, the immediate product of the reaction is a transition structure different from that which is ultimately

formed. An important example of this is the decomposition of martensite in steels during tempering. Whereas the tempering of iron–carbon martensite at temperatures above about 250° C apparently leads directly to the formation of a cementite–ferrite aggregate, at lower temperatures the formation of cementite is preceded by the precipitation of a transition carbide accompanied only by a limited depletion of the carbon content of the matrix. At temperatures below about 150° C, moreover, this transition state appears to be extremely persistent. It is with this so-called first stage of tempering that the present work is concerned and as a concise and substantially modern review of the whole tempering process has already been given[1] only the main features of this stage will be recalled.

The present conception of the mechanism of the first stage of tempering has stemmed largely from two types of X-ray diffraction study of the process. Using a single crystal technique in which the reflections constituting one martensite doublet could be separately recorded, Kurdjumov and Lyssak[2] showed clearly that martensite decomposes by a discontinuous process; i.e. instead of a general and gradual relaxation of the tetragonal martensite towards a cubic structure as had been indicated by the line shifts in previous Debye Scherrer investigations, a new low-carbon martensite is formed and, as tempering proceeds, grows in amount at the expense of the original high-carbon martensite. In a more extensive study, Roberts, Averbach, and Cohen[3] applied this technique to a series of plain carbon steels ranging from 0·78% to 1·43%C. Their results confirm those of Kurdjumov and Lyssak both with respect to the mechanism of the process and the carbon content of the new martensite; this is given as 0·25% and appears virtually independent of the carbon content of the original martensite.

The second contribution of diffraction studies has been the determination of the structure of the carbide which is precipitated during the first stage of tempering. Although reports of the detection of a new phase had been sufficiently numerous and convincing already to have refuted the early notion that tempering proceeded by the transition of tetragonal martensite to a cubic structure of the same carbon content, there was little indication of its structure until the notable investigation made by Jack.[4] Using a 1·3%C steel tempered at 120° C Jack obtained reflections consistent with a close-packed hexagonal phase isomorphous with ϵ-iron nitride and from which the designation ϵ-carbide was derived. The presence of this phase has since been detected in a range of iron–carbon alloys containing from 0·29 to 1·42%C by Folke and Nygren[5] whose values for the lattice constants agree with those reported by Jack.

The most recent and extensive investigation of the kinetics of first-stage tempering is that of Roberts, Averbach, and Cohen[3] who measured with high precision the length changes in specimens of iron–carbon alloys covering a wide range of carbon contents. Their results are given as plots of the fractional change in length as a function of the time of isothermal tempering, a correction being made for the presence of retained austenite and the influence on the length changes of its breakdown during the second stage of tempering.[6] In the temperature range of the first-stage process there results a steady contraction which is the more pronounced the higher the carbon content of the steel and of which the rate increases with increasing tempering temperature. Anaylsis of the results led to the suggestion that the ϵ-carbide and low-carbon martensite form an aggregate with an advancing plane front, a value of 16 000 cal/mole was assigned to the activation energy of the process. In a subsequent analysis[7] of the same precision length measurements based on a model which corresponds more closely to the mode of precipitation revealed by electron microscopy[8] the latter value has been revised to 26 000 cal/mole and the discrepancy between the time exponent of the reaction as determined experimentally (0·3) and that by the theory (0·5) has been removed.

While the main features of both the structural changes involved in the first stage of tempering and the kinetics of the process were already well established at the outset of the present work, uncertainty existed on a number of important aspects of the precipitation process. In particular the kinetic results of Roberts *et al.*[3] provoked further enquiry into the precise value and significance of the activation energy for the first-stage reaction. It was not at all certain even that the assignment of a unique value to the activation energy was justified and the position was further aggravated by the numerous and often widely conflicting values deduced from earlier investigations. Second, whilst the formation of a low-carbon martensite has been convincingly demonstrated in high-carbon steels there was no direct evidence that the same mechanism could operate in low-carbon alloys. In a steel containing less than about 0·6%C the diffraction lines associated with any low-carbon martensite which might be generated during the tempering would, apparently,[3] be extremely difficult to separate from those of the original martensite. The intriguing question is whether martensite which contains less than 0·25%C, in the condition in which it is formed by quenching, will temper at all. According to Roberts[3] the rate of tempering in the temperature range 22–123° C (72–250° F) falls linearly with decreasing carbon content to give, on extrapolation, a zero rate at 0·25%. The validity of the extrapolation seemed questionable since the most vital results, namely those for the lowest carbon alloy (0·29%), were also those in which the dimensional changes were smallest and least accurately measurable, and the implication of the extrapolation was not tested by an examination of the dimensional behaviour of a steel containing rather less than the critical amount of C (0·25%).

It appeared that further elucidation of these aspects of the tempering reaction might be provided by more detailed information on the kinetics of the process. Since an improvement in the already excellent dilatometric technique of Cohen and his collaborators seemed inconceivable, it was concluded that a more accurate evaluation of the kinetics of low-temperature tempering would require measurements to be made of the change in a property far more sensitive to atomic rearrangement than is density. Internal friction and electrical resistivity offered the greatest promise; of these, the former was rejected owing to the forbiddingly difficult problem of producing a specimen of suitable dimensions in the quenched condition.

Though applied with success to studies of precipita-

tion in other alloy systems, electrical resistivity measurement has been a much neglected approach to the problem of tempering. Since the notable work of Campbell[9] some forty years ago, little use appears to have been made of this technique for studying isothermal tempering; such results as have been recorded describe mainly the variation of resistivity with the temperature of tempering. The method has found useful application in recent times, however, in the study of the ageing of ferrite[10, 11, 12] and, towards the end of the period of the present research, some interesting results of resistivity changes during isothermal tempering were given by Jellinghaus.[13]

EXPERIMENTAL METHOD

The chemical analyses of the seven plain carbon steels used in the investigation are given in Table I. The steels were provided in the form of 1-in. or $\frac{5}{8}$-in. dia. rolled bars. Specimens cut at various intervals along the length of the bars were quenched and examined for homogeneity. Rods 10 in. long were cut off the stock, softened, turned down to 0·35 in. and then cold swaged to wire 2 mm dia. Specimens just over 10 cm long were cut from these wires.

The changes in electrical resistance during tempering were determined as a function of time, all measurements being made *in situ* at the tempering temperature. Since a change in temperature of 1° C causes the resistivity of a plain carbon steel to alter by about 0·25%,[14] resistance changes were determined by a differential method which consisted of measuring and comparing the potential difference across an unknown and a standard specimen which were wired in a series circuit. The standard specimen was identical to the test specimen in every way, except that it was quenched and tempered at 165° C for at least 1 day before use. A current of about 1 A was passed through the circuit from a 6 V battery; the resultant potentials across 5 cm at the centre of the specimens were 5–10 mV. Since this was measured to 0·1 μV, using a Cambridge vernier potentiometer, the accuracy of the readings was ± 0·001%.

The experimental procedure was as follows. All specimens were sealed in 3-mm dia. evacuated silica tubes and austenitized at 1 100° C for 20 min. Quenching was effected by rapidly withdrawing the tube from the furnace, fracturing one end, and inverting it, thus plunging the specimen into the quenching medium. Test specimens were rapidly transferred to a jig which carried the electrical connections and which in turn was inserted into an oil bath set at the temperature and controlled to ± 0·25° C. This operation took a maximum of 30 s. The results were expressed as the ratio $(\Delta R/R)$ of the change in resistivity to the initial resistivity of the steel. At the conclusion of the resistivity measurements, the martensite content of each specimen was measured using a Sucksmith magnetic balance.

PRELIMINARY EXPERIMENTS

Reproducibility of resistance measurements

During each isothermal tempering experiment the resistivity always changed perfectly smoothly with time, the scatter of values being quite negligible. The resistivity-change/time plots yielded by the same specimen after repeated heat-treatment or by different specimens of the same composition showed an almost complete reproducibility. Where a slight departure occurred, it could be traced to a variation in the martensite content of the specimen.

TABLE I Analyses of steels

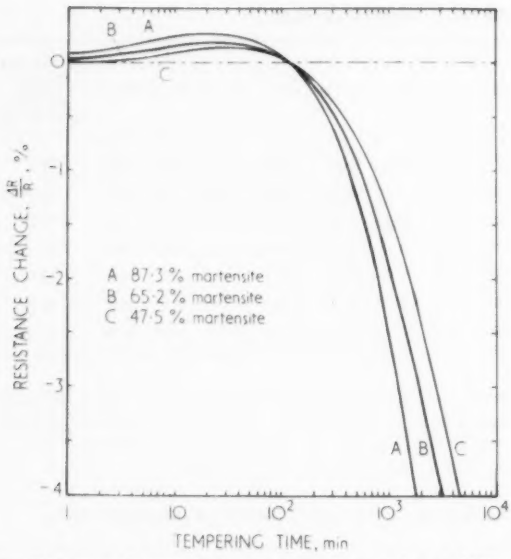
Steel	C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Martensite formed when quenched to 20° C, %
19	0·19	0·17	0·64	0·030	0·039	0·09	0·02	99·5
47	0·47	0·10	0·28	0·006	0·026	0·01	0·01	97·01
69	0·69	0·46	0·33	trace	0·025	nil	nil	93·8
92	0·92	0·46	0·28	0·003	0·02	nil	nil	87·5
127	1·27	0·09	0·16	trace	0·018	nil	nil	73·5
138	1·38	0·26	0·30	0·010	0·013	0·08	nil	65·5
150	1·50	0·33	0·37	0·010	0·017	0·06	0·05	50·64

The influence of martensite content on resistance changes

Typical values of the amount of martensite formed on quenching each of the steels to 20° C are given in column 9 of Table I. Since a considerable amount of austenite is retained in the higher-carbon steels, it was feasible that some decomposition of this phase might occur during tempering and thus contribute to the observed resistance change. To examine this possibility specimens of steel 138 were cooled to − 196° C by quenching in water and then in liquid nitrogen, to 20° C in water, and to 60° C in mercury. The resulting martensite contents were 87·3%, 65·2%, and 47·5% respectively. Immediately after the quench each specimen was tempered at 66° C, when the changes in resistance shown in Fig.1 were observed. It is clear that the effect of increasing the amount of martensite is to increase the magnitude of the resistance change, whether this be positive or negative. Figure 2 which is derived from the results of Fig.1 shows the relationship between the magnitude of the change in resistance $(\Delta R/R)$ and the martensite content of the specimens, after tempering for times of 25, 120, 500, and 1 000 min. This relationship can be represented by a family of straight lines which, when produced, pass through the origin. From this it was concluded that the retained austenite present in the quenched steel made no measurable contribution to the observed changes in resistance, and that the degree of the change after any given period is directly proportional to the martensite content of the specimen. Thus for a 100% martensite specimen the fractional resistance change P at any time, t, is given by:

$$P = \left(\frac{\Delta R}{R}\right) 100\,\%\ \text{martensite} = \left(\frac{\Delta R}{R}\right) M\,\%\ \text{martensite} \times \frac{100}{M} \quad \ldots\ldots\ldots(1)$$

where M is the actual martensite content of the specimen. By calculating all resistance changes in terms of this parameter P, a comparison is permitted between the resistance changes obtained on tempering different steels at the same temperature. Further, the influence of extraneous variations between the martensite contents of quenched specimens of the same steel could be eliminated.



1 *Resistance changes during isothermal tempering at 66°C of specimens of steel 138 quenched to various temperatures*

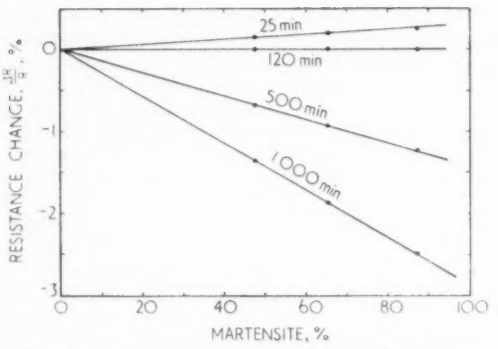
RESISTANCE CHANGES DURING TEMPERING

Samples of all seven steels were water-quenched to 20° C and then tempered at various temperatures between room temperature and 100° C, for times extending up to several weeks. The form of the resultant resistance changes as a function of time was found to vary with carbon content, and the following results have been grouped together on this basis.

Steels 19, 47, 69, and 92

The changes in resistance, P, observed during the isothermal tempering of steels containing up to 0·92%C are typified by the curves for steel 69 shown in Fig.3. In all four steels the effect of tempering is to cause a progressive decrease in the electrical resistivity. In agreement with the known kinetics of the first stage of tempering the reaction was observed to start without an incubation period and to proceed at a rapidly diminishing rate. It is apparent from the figure that at no temperature does the tempering reaction reach a distinct end point. At temperatures below 60° C the reaction is still far from complete even after several weeks. The curves for 100° and 120° C, on the other hand, do appear to tail-off after a few hours but thereafter follow an almost straight line on the logarithmic time plot. This behaviour was common to all four steels and is evidently due to the onset of the third stage of tempering which overlaps the first stage at these temperatures.[3, 5]

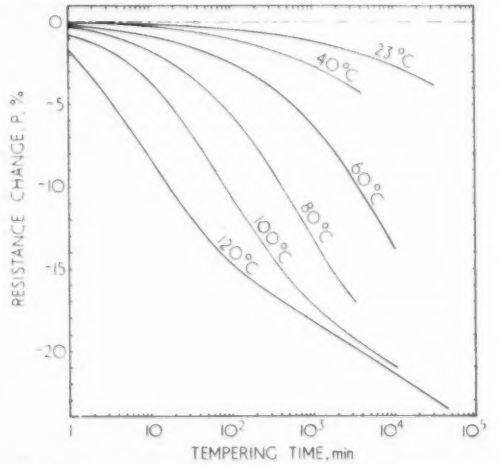
A comparison of the resistivity changes observed in the four steels is given by Table II from which the following trends can be recognized. Considering steels 47, 69, and 92, the resistivity change caused by tempering at 100° C is more pronounced the higher the carbon content of the steel. This is as would be expected if the decrease in resistivity is due to the depletion of the carbon in solid solution. On tempering at lower temperatures, however, this simple relationship no longer holds. After 100 min at 23° C,



2 *Dependence of resistance changes after the times indicated on martensite content; plotted from the results of Fig.1*

for example, the trend is in fact reversed, the resistivity change in steel 47 (0·544%) exceeding those of steels 69 (0·453%) and 92 (0·349%). After the same duration of tempering at an intermediate temperature such as 60° C, the greatest resistivity change is that shown by steel 69; that is, in order of increasing carbon content the resistivity change due to this treatment first increases from 1·577% for steel 47, to 2·448% for steel 69 and then decreases to 2·045% for steel 92. This complex pattern of resistivity changes can be considered in terms of the interplay of two factors. First, as indicated by the results for the 100° C tempering, the magnitude of the change which eventually occurs is the greater the higher the carbon content of the steel. Opposing this trend, however, the rate of resistivity change at temperatures of 60° C and below is the greater the lower is the carbon content of the steel. This is brought out in the final column of Table II which gives the mean rates of the change during the first 2 min of tempering.

Although the 0·19%C steel exhibited the same general form of resistivity changes as the higher-carbon steels, the magnitude of the decrease was at all temperatures considerably smaller, the greatest recorded value being rather less than 2% (Table II). The interpretation of these results is discussed later.



3 *Resistance changes during the isothermal tempering of martensite in steel 69*

TABLE II Resistivity changes during isothermal tempering

Steel	Tempering temperature, °C	*P* %, after indicated times 1 min	10 min	10^2 min	10^3 min	10^4 min	Initial rate, %/ min
19	100	0·118	0·426	0·889	1·397	1·825	0·063
	80	0·085	0·033	0·725	1·134	1·550	0·055
	60	0·060	0·245	0·501	0·840	1·257	0·048
	40	0·046	0·175	0·360	0·625	0·925	0·039
	23	0·033	0·127	0·290	0·502	0·741	0·030
47	100	0·679	2·640	7·112	11·456	13·809	0·433
	80	0·327	1·169	3·576	8·356	12·502	0·195
	60	0·143	0·598	1·577	4·050	8·833	0·138
	40	0·080	0·324	0·840	1·865	3·873	0·102
	23	0·039	0·196	0·544	1·135	1·923	0·060
69	100	0·803	3·534	10·711	17·257	20·906	0·487
	80	0·347	1·750	5·592	13·046	...	0·282
	60	0·227	0·875	2·448	6·525	13·772	0·138
	40	0·040	0·268	1·003	2·604	...	0·075
	23	0·029	0·148	0·453	1·151	2·635	0·054
92	100	0·831	4·323	13·212	21·387	26·504	0·623
	80	0·338	1·682	5·910	15·349	...	0·198
	60	0·169	0·572	2·045	6·251	...	0·102
	40	0·035	0·239	0·841	2·351	...	0·054
	23	0·017	0·106	0·349	1·005	2·360	0·024
127	100	0·571	3·939	14·448	24·500	31·491	0·529
138	100	0·452	2·865	11·298	20·492	...	0·301
150	100	0·035	1·796	10·295	19·751	26·950	0·135

TABLE III Comparison of three steels which exhibit an initial increase in resistivity during tempering

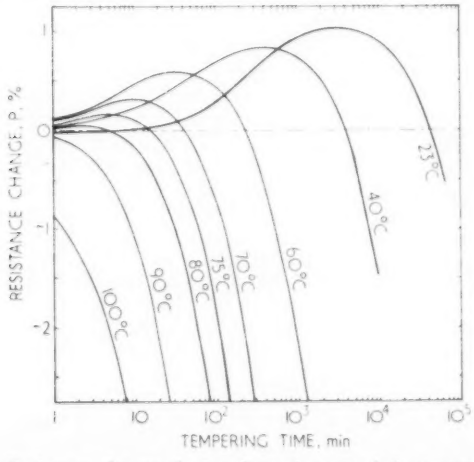
Steel	Tempering temperature, °C	Time to reach peak, min	Resistivity change (*P*) at peak, %	Time to cut *P* = 0 axis, min
127	80	1	0·007	2·5
	60	17	0·325	78
	40	150	0·431	1 000
	23	1 100	0·738	11 000
138	80	2·5	0·041	7·5
	60	35	0·535	220
	40	440	0·768	3 900
	23	4 000	1·042	44 000
150	80	10	0·624	41
	60	89	1·244	760
	40	1 500	1·504	14 500
	23	14 000	1·934	> 100 000

Steels 127, 138, and 150

Referring to Fig.4, the curves for the change of P in steel 138 tempered at 90° and 100° C exhibit the same form as that observed at all temperatures for the lower-carbon steels. However, during the tempering of this steel at temperatures of 80° C and below the value of P becomes positive, passes through a maximum and then decreases rapidly to follow the same form of curve as at 90° and 100° C. Eventually the curves for all the temperatures from 23° C up to 100° C become mutually parallel and remain so throughout the remainder of the reaction or until further distorted by the inception of the third stage of tempering.

Initial peaks in the variation of P with tempering time were also observed in steels 127 and 150, but again only at temperatures of 80° C and below. From the data of Table III it can be seen that the extent of the positive change in resistivity is a function of the initial carbon content of the martensite. Thus the height of the peak, the time to reach it, and the time at which the curve cuts the $P = 0$ axis decrease progressively from steel 150 to steel 127, while for steels containing below 0·92%C the value of P never becomes positive.

The resistance changes at 100° C, when no maxima occurred, were also found to be influenced by the initial carbon content of the martensite. The initial rates of P at this temperature were found to decline progressively from steel 127 to steel 150 (Table II), an effect fully consistent with the trends exhibited at lower temperatures in the lower-carbon steels.



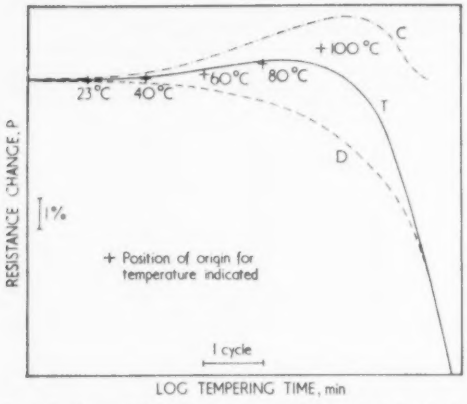
4 *Resistance changes during the early part of the tempering process in steel 138*

DISCUSSION

Tempering of high-carbon martensites

The most interesting feature of the resistance changes which occur during the tempering of the higher-carbon martensites is the initial increase observed on tempering at 80° C and below. The question arises whether the variation in the form of the plots of resistance/tempering-time is caused by a change in the underlying mechanism or whether it is simply a manifestation of the effect of temperature on the rate of the reaction which, in turn, alters the point to which the reaction has progressed within the first minute. The fact that the curves for a particular steel eventually attain a common slope on a log time plot suggests that the tempering process remains essentially the same over the temperature range examined (23–100° C). If this be so, it should be possible, for any steel, to superimpose the curves determined at various temperatures, by an appropriate shift of the origin. This test has been applied to the data for steel 138 (Fig.4), with the result indicated by the curve shown as a continuous line in Fig.5. On this plot, the progress of the resistance change at any temperature is that given by the portion of the curve to the right of the appropriate origin. Judging by the closeness with which the curves of steel 138 can be fitted on the common curve T of Fig.5, it seems unlikely that the mechanism of tempering in this steel is modified by variation of the tempering temperature up to 100° C. The same conclusion was drawn from corresponding tests made on the results for steels 127 and 150 which also display initial increases in resistivity during tempering at the lower temperatures.

In considering the cause of the initial increase in resistivity which appears as a fundamental effect in the tempering of the higher-carbon martensites, reference can usefully be made to analogous observations of the decomposition of supersaturated solutions in other alloy systems. Anomalous resistance changes are well known to occur during the age hardening of many alloys; in some cases a definite peak is found



5 *Contributions of the coherency effect (C) and of the depletion of carbon in solution (D) to the total resistance change (T) during the tempering of steel 138*

in the resistivity curve, while in others, the effect appears as an inflection. According to Geisler[15] these peaks or inflections have a common significance in that both can be attributed to a positive component of the resistivity change superimposed upon the normal decrease due to the depletion of solute. In discussing the resistivity changes observed during the ageing of an aluminium–copper alloy, Mott[16] has pointed out that precipitate particles, whose size approximates to that of the wavelength of a conducting electron, should have an abnormally high resistivity. Thus, as the average particle size passes through this critical value (5–10 Å), so the positive component of the resistance change will pass through a maximum. As a general explanation of the anomalies observed in the resistivity changes accompanying the decomposition of solid solutions, Mott's suggestion is inadequate since in Al–Ag alloys, for example, the particle size associated with the maximum in the resistivity curve is at least 100–1 000Å[17] and further, it is difficult to appreciate why on this basis an anomalous peak or inflection is not an invariable feature of the resistivity changes for all precipitation processes. In particular, the strength of the positive component would not be expected to vary with the degree of supersaturation as is clearly the case in the tempering reactions which have been studied.

A more likely cause of the increase in resistance during tempering is the lattice strain of the matrix which accompanies precipitation[18] since, as is well known, the flow of electrons through a metallic conductor is very sensitive to discontinuities in the periodicity of the crystal lattice. The most important strains are probably those induced by the maintenance of lattice coherency between a transition precipitate and the matrix.[15] Such coherency strains would be expected to build up to a maximum as the precipitate grows and then be relaxed as it breaks away from the matrix to become a discrete particle. If the resistivity change due simply to the depletion of the carbon in solution in the martensite be assumed to follow the same course as the dilatation which accompanies tempering[3] then it can be described conjecturally by the broken line *D* of Fig.5. When the resistivity changes due to this effect alone are subtracted from the measured values (curve *T*), a positive component of resistivity change of the form of curve *C* results. In as much as curve *C* rises to a maximum and then decreases to zero, it conforms to the pattern predicted by the above argument when the effect of the coherency strains are summed over all the growing particles.

Diffraction evidence that ϵ-carbide is precipitated in coherent form has been obtained by Jack[4] and subsequently by Folke and Nygren[5] who found that the reflections did not have the same mutual intensity ratio as that normally observed for hcp phases. The relative weakening of the usual intensity of any reflection was a function of the angle between the particular reflecting plane and the $(10\bar{1}1)$. From this Jack inferred that the precipitate took the form of a stringlet the axis of which is normal to a $(10\bar{1}1)$ plane. Further, as the interplanar spacings of these planes are almost identical with the (101) of the martensite, Jack proposed that during the precipitation of ϵ-carbide the $(10\bar{1}1)$ of the precipitate is parallel to and coherent with the (101) of the matrix.

Since the lattice parameters of martensite vary with carbon content, the perfection of matching between the $(10\bar{1}1)$ of the carbide and the (101) of the martensite will also depend upon the carbon concentration of the martensite. Using the data summarized by Roberts[19] the spacings of the (101) of martensite have been calculated for the steels for which the resistivity changes during tempering are known. These values, together with an indication of the degree of misfit between the $(10\bar{1}1)$ of the carbide and the (101) of the martensite, are given in Table IV. A distinct correlation is to be seen between the degree of misfit and the incidence of an anomalous resistivity change; only when the misfit is less than about 0·5% does an initial resistivity increase occur during tempering. According to this picture it is presumed that in steels in which the degree of misfit exceeds this value, the precipitate particles break away from the matrix so early that any increase in resistivity due to coherency is outweighed by the normal decrease due to solute depletion. Where this happens, the coherency effect would be expected to lead not to an increase in resistivity as during the tempering of the higher-carbon steels but instead to a diminution in the rate at which the resistivity initially falls. This is borne out by the measured resistivity changes in steels containing 0·92%C and less (Table II). On tempering at 60°C or below the rate of fall in resistivity is greater in steel 47 than in steel 92; the initial rate measured in steel 92 is, indeed, rather less than that for the very low carbon steel (0·19%).

From X-ray line broadening, Werner, Averbach, and Cohen[20] have estimated quantitatively the lattice strain in martensite as a function of carbon content and tempering treatment. Of particular interest are their results for the isothermal tempering of a 0·96% carbon steel which reveal that at 93°C and 149°C the strains pass through peaks which, following the same general pattern as the resistivity peaks, occur earlier and become less distinct as the tempering temperature is raised. Assuming, with the authors, that the initial increase in lattice strain is associated with coherent precipitation, their results provide good support for the present argument that the observed peaks are due to coherency strains. On the influence of carbon content, however, the requirements of the present argument that the degree of coherency should

increase with carbon content conflicts with Werner's conclusion that between 0·63% and 1·43% this variable has a negligible influence on the lattice strain. Without challenging the broad truth of this conclusion there is a difficulty in that it is not known how sensitive the resistivity may be to coherency strain, and the evident scatter in the measurements on which the assertion is based might mask a systematic variation of lattice strain with carbon content of a magnitude sufficient to account for the observed influence of carbon on the resistivity peaks.

TABLE IV Interplanar spacings of (101) planes in carbon martensite

Carbon content of steel, %	Investigator	$d_{(101)}$ kX	Degree of misfit relative to $d_{(10\bar{1}1)}$ ε-carbide, %	Anomalous resistance peaks during tempering
ε carbide	Jack,[4] Folke[5]	2·07$_4$	...	Anomalous X-ray diffraction patterns
1·3 (approx)	Jack[4]	2·06	0·68	
0·19	Steel 19	2·02$_9$	2·17	Nil
0·21	Jellinghaus[13]	2·03$_0$	2·13	Nil
0·41	Jellinghaus[13]	2·03$_7$	1·79	Nil
0·47	Steel 47	2·03$_5$	1·69	Nil
0·69	Steel 69	2·04$_6$	1·35	Nil
0·79	Jellinghaus[13]	2·04$_9$	1·20	Nil
0·92	Steel 92	2·05$_4$	0·97	Nil
1·27	Steel 127	2·06$_1$	0·39	Initial increase
1·38	Steel 138	2·07$_0$	0·19	Initial increase
1·50	Steel 150	2·07$_4$	Nil	Initial increase

Resistance changes in low-carbon martensite

The immediate significance of the resistivity results for steel 19 is that some atomic rearrangement does occur during tempering in a martensite containing less than 0·25%C. It will be recalled that the rate constant for the first stage of tempering as derived from measurements of the associated length changes was shown to decrease with decreasing carbon content yielding, on extrapolation, a value of zero at about 0·25%C.[3] The implication that martensite of lower-carbon content is not susceptible to tempering agrees neatly with the observation of an apparently metastable 0·25%C martensite[2, 3] as a product of the tempering of high-carbon steels, and the failure to detect, either by X-ray diffraction[5] or electron microscopy,[8] the presence of ε-carbide in a 0·15%C martensite. From this it might be presumed that martensite containing less than 0·25%C should exhibit no change in resistivity at least until at temperatures above about 250° C when the precipitation of cementite may commence.[3, 5] On the other hand, supersaturated ferrite, containing at the most only about 0·025%C in solution, undergoes considerable modification during ageing near room temperature with or without prior deformation and exhibits changes in many physical properties including electrical resistivity.[10–12] It would seem reasonable from this to expect resistivity changes at least as marked as those observed in ferrite to occur during the tempering of low-carbon martensites.

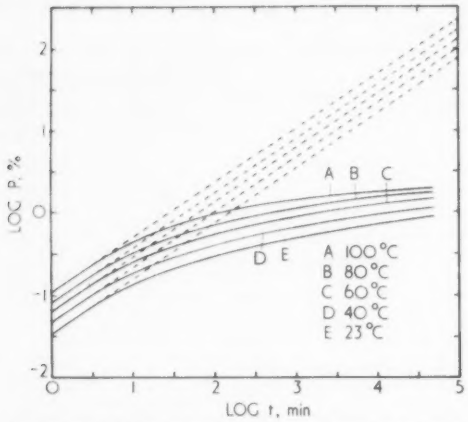
As can be seen from Table II, the magnitude of the resistivity decrease in steel 19 is very much smaller than that of the higher-carbon steels. After tempering for 10^4 min at 100° C the resistivity of steel 19 had decreased by 1·8% whilst that of steel 47, for example, had fallen by as much as 13·8%. On the assumption that the decrease in resistivity arises from the removal of carbon from solution in the martensite these changes can be expressed in terms of the amount of carbon removed, provided that the variation of resistivity with the carbon content of martensite is known. Over the range of alloys used in the present investigation, this relationship was found to be linear,[21] and the absolute resistivity ρ in $\mu\Omega cm^2/cm$ can be expressed by

$$\rho = 21{\cdot}87C + 17{\cdot}01 \quad \ldots\ldots\ldots\ldots (2)$$

where C is the wt-% carbon content of the martensite.

To check the validity of this relationship at carbon contents below 0·19%, the resistivity of steel 19 in the freshly quenched condition was compared with that after tempering for 3 days at 650° C. After this treatment the steel would consist of ferrite containing of the order of 0·025%C, together with a little cementite. The measured decrease in resistivity of 16·06% is in remarkably good agreement with that predicted by the above expression (16·98%); exact agreement is not to be expected since the presence of cementite in the fully tempered steel would, as is found, cause the measured resistivity to be a little greater than that for ferrite alone. Thus it is established that equation (2) holds for all values of carbon down to 0·025% and can be used to relate an observed decrease in resistance to the depletion of the dissolved carbon, even in steel 19. The resulting value for the decrease in carbon content of the martensite of steel 19 after tempering for 10^4 min at 100° C is 0·018% compared with 0·170% for steel 47 after the same treatment. The marked disparity between these values suggests a radical difference between the underlying tempering mechanisms.

The magnitude of the resistivity change in steel 19 (1·8% after 10^4 min at 100° C) is similar to that which accompanies the ageing of supersaturated ferrite, typical values for which are 1·7%[11] and 2·8%[12] after quench ageing and 2·88% after strain ageing[12] for about 10^4 min at 90° C. Although the overall decrease in resistivity is much the same whether or not the ferrite is deformed before ageing, the kinetics of quench ageing differ significantly from those of strain ageing. The latter process has many times been shown to conform to a $t^{2/3}$ law as predicted by the theory which associates the incidence of strain ageing in iron with the diffusion of carbon (or nitrogen) to dislocations.[232] On the other hand for quench-ageing, which involves the precipitation of carbide,[23, 24] observed values of the time exponent have ranged from 1·2 to 1·7.[11, 12, 25] A direct comparison of the two processes in the same 0·018%C steel was made by Dahl and Lücke[12] who found that a deformation of 5·3% made immediately after quenching reduced the time exponent for subsequent ageing, as measured by the change in electrical resistivity, from 1·26 to 0·76. The time exponent for the tempering of steel 19, as given by the slope of the initial parts of the curves of Fig.6 is almost exactly 2/3, i.e. the value associated with strain ageing. This suggests that the tempering process in low-carbon martensite consists initially, at least, in the segregation of carbon atoms at dislocations. Unfortunately, it was not possible to compare the time exponent for tempering in steel 19 with those for the higher-carbon steels, in which carbide precipitation is known to occur, as the initial rates of



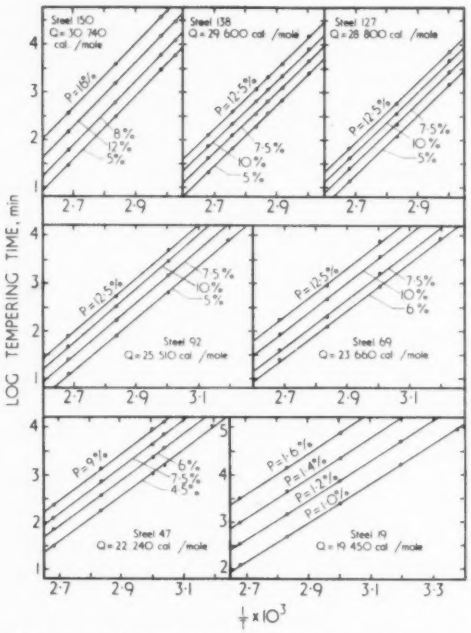
6 *Relationship between log* P *and log* t *at various temperatures for steel 19*

the resistivity changes in the latter varied in a rather complex manner with temperature. Since martensite forms by a shear mechanism the density of dislocations in this structure can be envisaged as being of the same order as in cold-worked ferrite. Thus, it is reasonable that the segregation of carbon atoms at dislocations should afford a competitive means for their removal from solid solution. If, moreover, the precipitation of carbide should be difficult for some reason, e.g. the coherency strains in this alloy are expected to be excessive (Table IV) then the formation of carbon atmospheres at dislocations will become the dominant process. Evidence of the delicate balance which obtains between the interaction of carbon atoms with dislocations and with the nuclei of the carbide phase, respectively, is provided by the observation of Wilson[26] that if a medium-carbon martensite (steel 47 of the present series) is sufficiently cold worked, the normal precipitation of ϵ-carbide in the first stage of tempering can be restrained.

The conclusion that the resistivity change during the tempering of the 0·19%C steel is due to the migration of carbon atoms to dislocations rather than the precipitation of carbide, is in accord with the observed stability of the low-carbon martensite formed along with ϵ-carbide during the tempering of high-carbon steels. Further, if tempering is followed by the measurement of the variation in such structure insensitive properties as density (or associated length changes) and lattice constants[3] then according to the present view, it is to be expected that changes would be observed in high-carbon martensites, in which tempering causes a phase change, but not in low-carbon martensite in which the process is the clustering of carbon atoms. By the same reasoning, it is understandable that no carbide precipitation has been observed in low-carbon martensite after tempering in the normal first-stage tempering range[5, 8, 27] yet its presence has been detected in quench-aged ferrite of much lower carbon.[23, 24]

Activation energy for the first stage of tempering

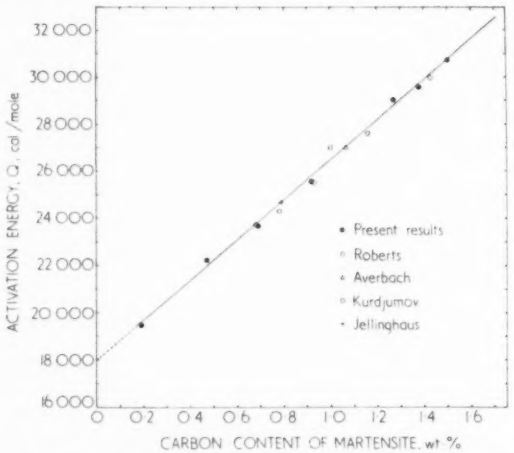
Despite the initial anomalies, the curves of resistivity change *v.* log time for each of the steels at the various temperatures become parallel after a time and remain so over a wide range of values of P. The



7 *Relationship between log* t *and* 1/T *after various degrees of tempering for the seven plain carbon steels*

activation energy for this part of the reaction was determined by the usual method of plotting the logarithm of the time to reach a certain stage of the reaction against the reciprocal of the absolute temperature. If there be a unique activation energy this plot should yield a straight line, from the slope of which the activation energy can be evaluated.

Figure 7 shows the results obtained for each of the steels at four different values of P. To within the experimental limit, every plot of $1/T$ *v.* log t gave a straight line. Further, over a wide range of P values the lines for any one steel are parallel; thus for each steel there is a unique value of activation energy for



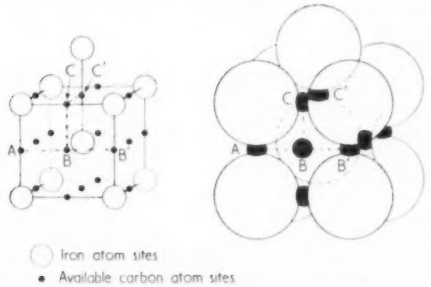
8 *Relationship between the activation energy of the first stage of tempering and the carbon content of the martensite. Comparison of present results (Fig.7) with those of other investigators (Table V)*

TABLE V Previous determination of activation energy of the first stage of tempering

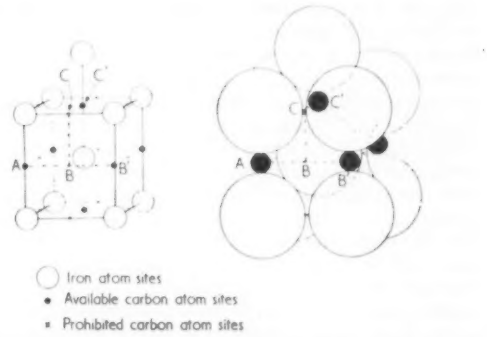
Investigator	Method	Carbon content of steel, %	Reported value of Q, cal/mole	Corrected value of Q, cal/mole	Re-calculated value of Q, cal/mole
Averbach and Cohen[6]	Precision length	1·07	9 050	27 000[12]	...
Kurdjumov and Lyssak[13]	X-ray diffraction	1·00	27 000	...	...
Roberts *et al.*[3]	Precision length	0·68	16 000	26 000[7] (± 3 000)	23 700
		0·78			24 300
		0·93			25 500
		1·16			27 600
		1·43			30 000
Jellinghaus[13]	Electrical resistance	0·79	20 600	...	24 650

the tempering process. The resultant values for the activation energy are represented by the closed circles of Fig.8 in which they are plotted against the carbon content of the martensite. The activation energy is seen to increase linearly with the carbon content over the whole composition range investigated.

A summary of previously reported activation energies for first stage tempering is given in column 4 of Table V. The results obtained by applying Zener's correction[29] to the data of Averbach[6] and the amendments suggested by Lement and Cohen[7] to the results of Roberts[3] appear in column 5. Most of these investigators have assumed the activation energy to be invariant with the carbon content of the steel and have associated it with the activation energy for the diffusion of carbon in ferrite. For example, Roberts has taken an average value for all five steels. However, on close scrutiny it is found that the slope of the plot of the rate constant (from which the activation energy was evaluated) against $1/T$ varies significantly from steel to steel (Fig.14 of ref. 3). By taking the best slope of this plot for each individual steel, and correcting according to Lement and Cohen,[7] the values listed in column 6 of Table V were calculated. While these values are only approximate, it is apparent that the general trend of the results is to indicate that the activation energy increases with the carbon content of the martensite. Although the value of 20 600 cal/mole reported by Jellinghaus[13] for a 0·79%C steel is indeed in good agreement with the activation energy for the diffusion of carbon in ferrite, it would seem that in deriving this value the data obtained for tempering at 40° and 20° C have been ignored even though the latter results were apparently reproducible. Taking account of the 20° and 40° C points on the plot of the rate constant against $1/T$ (Fig.9 of ref.13), an activation energy of



9 *Interstitial diffusion paths for carbon atoms in bcc ferrite*



10 *Interstitial diffusion paths for carbon atoms in bct martensite*

about 24 650 cal/mole is obtained. With these amendments, the previously determined activation energies are seen from Fig.8 to be fully consistent with the straight line yielded by the present results.

Since the activation energy for tempering proved to be constant throughout the major part of the process, it is reasonable to associate the unique value obtained for each steel with the underlying mechanism involved, i.e. the diffusion of carbon through the martensite. It follows, therefore, that the activation energy for the diffusion of carbon in martensite increases linearly with carbon content. This behaviour is in marked contrast to the effect of increasing the amount of carbon in solution in austenite which is to reduce the activation energy for carbon diffusion.[30] Now the principal effect on the crystallographic structure of bct martensite brought about by raising its carbon content, is to increase the axial ratio. It is of interest to consider the probable effect of such an increase in the degree of tetragonality on the activation energy for the diffusion of carbon through the lattice, assuming that to a first approximation the carbon atoms behave like hard spheres.

In ferrite the majority of the carbon atoms occupy the octahedral interstices at the mid-points of the cell edges (0, 0, ½; 0, ½, 0; ½, 0, 0) and at the face centres (½, ½, 0; ½, 0, ½; 0, ½, ½),[31, 32] the remainder being in the tetrahedral positions midway between any two adjacent octahedral sites on a cell edge or face centre (0, ¼, ½; etc.). The position of the available octrahedral sites are illustrated in Fig.9. Since the maximum solubility of carbon in ferrite is very small, only one in several thousands of these available sites is occupied by a carbon atom; hence all neighbouring sites to any particular carbon atom can be assumed to be vacant. The diffusion path of a carbon atom from one octahedral site to another will be via the tetrahedral positions midway between them; i.e. the paths *A–B–B′* or *A–B–C–C′* in Fig.9. The activation energy for diffusion is to be considered as an energy barrier against the transfer of a carbon atom from one interstitial site to another. All that is necessary in the movement of a carbon atom from any octahedral site to the adjacent tetragonal site is that it should move aside from the two iron atoms pressing most closely upon it.[33] Thus the activation energy will be mainly associated with the forcing apart of the two closest iron atoms at the new octahedral site.

In tetragonal martensite the carbon atoms are

situated in the octahedral interstices at the mid-points of the log cell edges 0, 0, ½, and at the centres of the faces normal to these edges ½, ½, 0.[33, 34] Even in a martensite containing 1·7%C, still only one in 12 of the available sites are filled, and hence all neighbouring sites to any carbon atom may be considered to be empty. The diffusion path of a carbon atom from one available site to another must pass through at least two tetragonal sites, and one prohibited octahedral position, i.e. the paths A–B–B' or A–B–C–C' in Fig.10 where sites B and C are prohibited. Although some of the tetrahedral sites in martensite have been enlarged and others decreased as compared to the equivalent sites in ferrite, the movement of a carbon atom from any octahedral position to an adjacent tetragonal position remains relatively easy.[33] On the other hand Petch[33] has demonstrated that for the prohibited octahedral sites, the distance between the centre of the interstices and the nearest iron atoms is decreased as the carbon concentration is raised. Thus the energy barrier against the passage of a carbon atom through the prohibited octahedral sites would be expected to be greater than that opposing the passage of a carbon atom in ferrite, and to be raised as the carbon content of the martensite is increased. This is in keeping with the experimentally determined relationship of Fig.8.

From the relationship of Fig.8 the activation energy for carbon diffusion (Q_c) in martensite can be expressed as a function of the carbon content (C) by:

$$Q_c = 8\,500\,C + 18\,000 \text{ cal/mole} \quad \ldots\ldots\ldots(3)$$

The value of 18 000 cal/mole which equation (3) yields for the value of Q_c corresponding to 0%C lies somewhat below the activation energy for the diffusion of carbon in ferrite obtained from internal friction measurements by Wert.[35] In view of the extreme precision with which Wert's value of 20 100 cal/mole, was obtained and the evident reliability of equation (3) at least above 0·19%C, the disparity between the two values, though small would seem to be significant. A possible explanation of this disparity is that at low concentrations, the carbon in martensite is incompletely ordered.[36] Although it is generally assumed that the axial ratio of martensite decreases linearly to unity as the carbon content is reduced to zero, no direct measurements of lattice parameters have been made at carbon concentrations below about 0·3%.[20] It may be, therefore, that at low-carbon contents the activation energy for the diffusion of carbon in martensite is reduced to below that for ferrite, i.e. Q_c decreases with increasing concentration as is found for austenite[30] and which conforms to the usual trend for solutes in random solution. Only at carbon contents at which the martensite is predominantly tetragonal would Q_c be expected to increase with carbon content according to the reasoning depicted in Fig.10.

An alternative view of this discrepancy of some 2000 cal/mole is suggested by the fact that even in ferrite the activation energy for ageing lies below that for carbon diffusion by a similar amount [25, 37] and in fact agrees closely with the extrapolated value of Q_c given by equation (3). This could mean that the values of Q_c for tempering are a little lower than the activation energy for carbon diffusion at all carbon concentrations. Until the cause of the discrepancy in the case of ferrite has been elucidated, however, the merit of such an assumption is difficult to judge.

ACKNOWLEDGMENTS

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Surface fracture markings on alpha iron crystals

C. F. Tipper, Sc.D., D. I. Dagg, B.Sc., and O. C. Wells, Ph.D.

SURFACE MARKINGS on fractured crystals are of two kinds. One is common to crystalline and amorphous materials and is regarded in consequence as being only indirectly related to the crystalline nature of the solid. The other kind follows definite crystallographic directions. The markings may take the form of secondary cracks, or steps, of varying dimensions. Considerable work has already been done on their identification.

The work to be described is confined to the study of cleavage fractures in α-iron, which frequently occur on planes parallel with the cube faces of the body-centred cubic lattice when the metal is broken at low temperatures, when embrittled by hydrogen, or at normal atmospheric temperatures when alloyed with silicon. The material used in this investigation was a low-carbon iron, a decarburized mild steel, and a silicon iron containing 4·5%Si, all in the form of single crystals which were broken in tension (cylindrical specimens) or bending (flat strips). The iron and decarburized mild steel were broken in liquid nitrogen; the silicon iron fractured by cleavage at room temperature, but many of the crystals investigated were tested at low temperatures to obviate distortion before fracture. All materials, however, showed the presence of Neumann lamellae on examination after fracture.

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SYNOPSIS

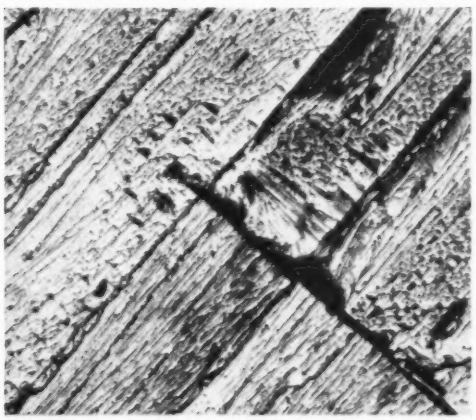
The paper summarizes the results of observations, making use of normal metallographic methods and of the electron microscope, for the study of cleavage fractures in α-iron. Most of the striations on the surface can be attributed to the presence of Neumann lamellae, i.e. twins on planes of indices {112}, which have formed just before fracture or during the course of fracturing, or to non-crystallographic differences of level, which are common to fractures in both crystalline and amorphous substances.

1625

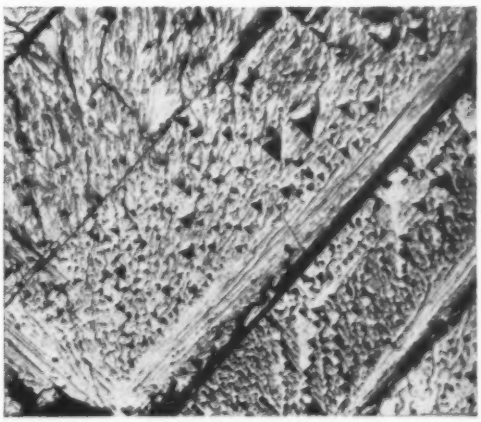
The work may conveniently be considered in three parts. The first describes results of observations based on normal metallographic and crystallographic methods. The second gives some preliminary results obtained with a scanning electron microscope developed in the Engineering Department, Cambridge University[1,2,3] and compares the photographs obtained by this means with those of a normal optical microscope and with structures revealed by the replica method of electron microscopy. The third part gives a summary and possible interpretations of the structures observed.

RESULTS OBTAINED USING NORMAL METALLOGRAPHIC AND CRYSTALLOGRAPHIC METHODS

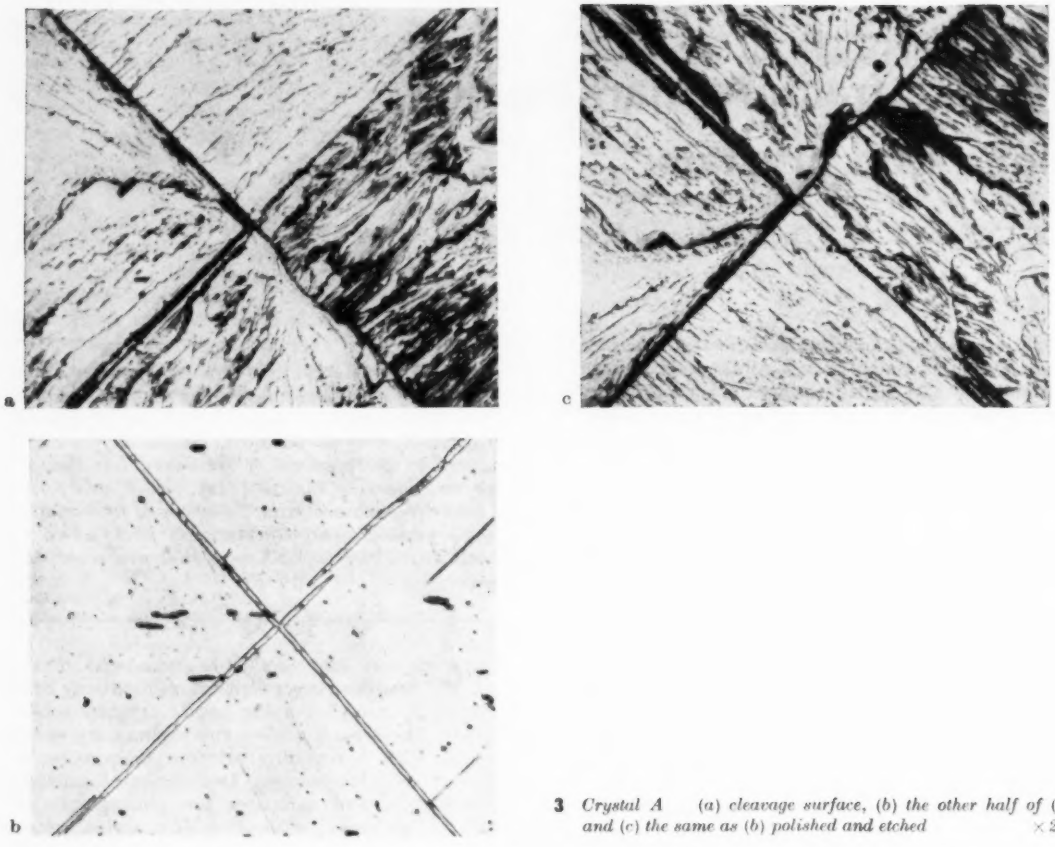
Figures 1–3, and 5, are characteristic of the structures investigated and show three main types of markings:



1 *Block system, river markings, and pits on cleavage surface of carbonyl iron* × 150



2 *Marked pit flake formation on cleavage surface of carbonyl iron* × 150



3 *Crystal A* (*a*) *cleavage surface*, (*b*) *the other half of* (*a*), *and* (*c*) *the same as* (*b*) *polished and etched* ×200

(*a*) marked striations intersecting at 90°, forming rectangular blocks which are associated with differences in level; (*b*) striations which fan out from centres of fracture origins, sometimes referred to as a 'river pattern',[4] a feature which is common both to crystalline and amorphous substances of widely differing structures and compositions; (*c*) much smaller markings, which somewhat resemble etching pits, but which often project above the surface. Figure 3*a* and *b* are of the opposite surfaces of the same crystal. The pattern on one face is the mirror image of that on the other.

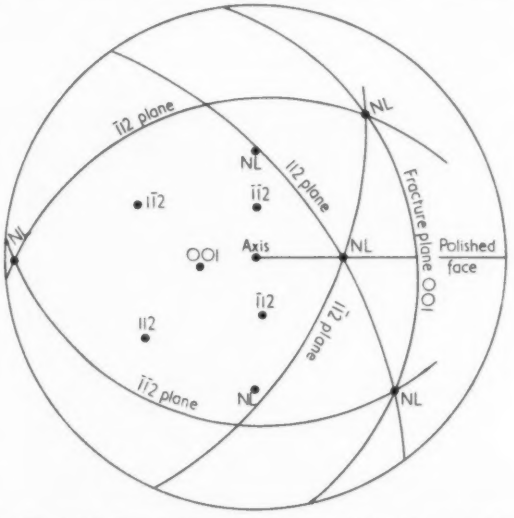
All these structures have been recorded in both monocrystalline and polycrystalline material of a variety of compositions and treatments. Zapffe and Moore[5] showed all three on the surface of irons embrittled by hydrogen. In discussing the results of this investigation Barrett and Derge[6] attributed the larger, straight line markings to the presence of Neumann lamellae, i.e. twins on {112} planes.

Tipper and Sullivan[7] attributed the large striations on cleavage fractures of silicon ferrite to the intersection of Neumann lamellae on these surfaces.

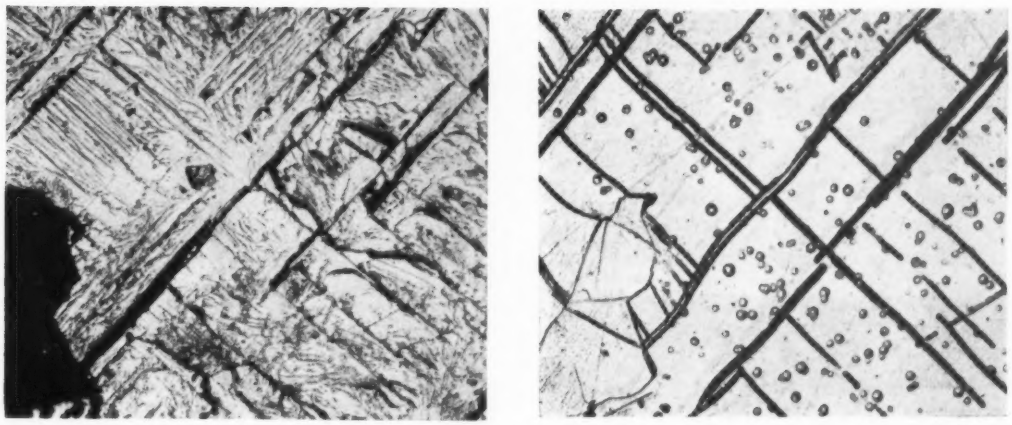
The small markings have not been identified. Crussard *et al.*[8] have shown electron micrographs of replicas obtained by the carbon deposition method on fracture surfaces and they refer to the projections as 'tongues'.

It will suffice to describe the results obtained on two crystals, one broken in tension, *A*; one in bending, *B*.

Identification of the large blocks was made by photographing and measuring the inclination of the marks on the fracture surface, relating them to structures developed after grinding and polishing this surface, and to surface markings such as Neumann



4 *Crystal A, the points marked N L were obtained by measuring traces of lamellae on polished surfaces*



5 *Crystal B (a) fractured surface, and (b) same field as (a) ground and polished. The distortion in the bottom left corner was due to a small intruded crystal* ×150

lamellae, which appeared on a surface polished previous to fracture, or on sections ground and polished after fracture.

The fracture surfaces of crystal *A* (shown in Fig.3*a* and *b*) was in a strip of decarburized steel, 5 cm long × 1 cm wide × 2 mm thick, which was broken by bending in four-point loading in liquid nitrogen. The beam was not monocrystalline, but a single crystal occupied the whole cross-section where fracture actually occurred. The polished face was on the tension side and two sets of Neumann lamellae formed on this face, but no slip bands. The beam was slightly distorted, but the fracture surface was plane, apart from local irregularities.

One of the fracture surfaces was mounted, ground, polished, and etched. Figure 3*c* shows the appearance of the surface at the exact location of Fig.3*a*. Neumann lamellae occupy the positions previously held by the steps. The polished surface was also lightly ground and repolished and two further sections were examined at right-angles to this face, i.e. through the strip thickness. Finally, the face opposite to that originally polished, i.e. the compression side of the beam, was also polished.

A stereographic projection was made incorporating all these measurements in relation to the crystal structure. Figure 4 shows that all the plotted points lie on possible planes of indices {112} inclined to the fracture plane (001), at 35–36°.

Crystal *B* was in the form of a cylindrical bar (0·15 in. dia.) of carbonyl iron broken in tension. The rectangular block system was very marked although there was some distortion due to the presence of intruded small crystals. The fracture surface of this crystal is shown in Fig.5*a*. Figure 5*b* shows the same field after removal of 0·002 in. parallel to the fracture face. There is more evidence of distortion in this crystal and less good agreement between the surface steps and the Neumann lamellae. It must be remembered, however, that the more material removed the less good agreement is likely to be.

Reference to Fig.4, crystal *A*, shows that traces of Neumann lamellae corresponding to the planes (112) and $(1\bar{1}2)$* appeared on all polished sections and on the fracture, which they intersect at 90° to each other. Two other planes $(\bar{1}12)$ and $(\bar{1}\bar{1}2)$, also intersect the fracture plane at 90° and a few strongly marked lamellae corresponding to the intersection of these planes on the originally polished face were recorded, as well as on the corresponding face on the compression side, which was polished subsequently. Traces of all four planes should have appeared in sections cut through the strip thickness, but only two could be seen on two independent sections and these agreed more closely with the $(1\bar{1}2)$ and (112) planes than with $(\bar{1}12)$ and $(\bar{1}\bar{1}2)$. Should the maximum shear stress law apply to twin formation, twinning on the $(1\bar{1}2)$ $[\bar{1}1\bar{1}]$ and (112) $[\bar{1}\bar{1}1]$ planes and directions would be expected in preference to any other, and it is probable that these planes contributed to the block formation in this crystal.

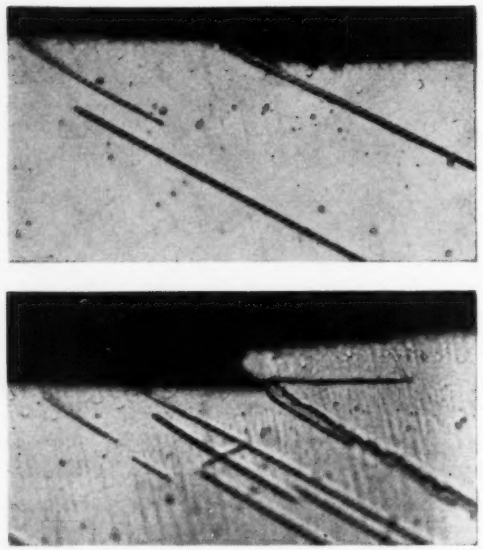
The lamellae were more numerous on the surfaces of the test specimen. Few appeared in the centre of the strip except adjacent to the fracture surface. It has been noticed both in tensile and bend tests that many of the lamellae are not extensive and may be regarded as consisting of bars or plates of limited dimensions rather than of planes traversing the full section.

Sections of both crystals were cut in order to study the intersections of the lamellae with the fracture surface, and to determine the angle which the sides of the blocks made with the cleavage face. The steps referred to, reflect the light in a regular manner. Owing to their small dimensions, attempts to measure this angle were only partially successful in a two-circle goniometer. The mean was about 36–38°.

A previous measurement of the angle of intersection by Zapffe[9] is recorded and Berry [10,16] has recently determined 35° for the intersection of the steps on the cleavage plane on sections cut perpendicular to a [110] direction. Both Berry and Klier[10,11,16] showed steps at the intersections of Neumann lamellae and the cleavage plane and, in some instances, cracks followed the twin interface, leading to the conclusion that cleavage also occurs on planes of indices {112}. This plane, however, is also one of the possible slip planes in the iron lattice.

Sections of the fracture of crystal *A* were made parallel with the previously polished face. Figure 6*a* and *b* show the steps following the intersections of the

* Note that these planes intersect the polished face of the specimen at the same angle and are indistinguishable on this face



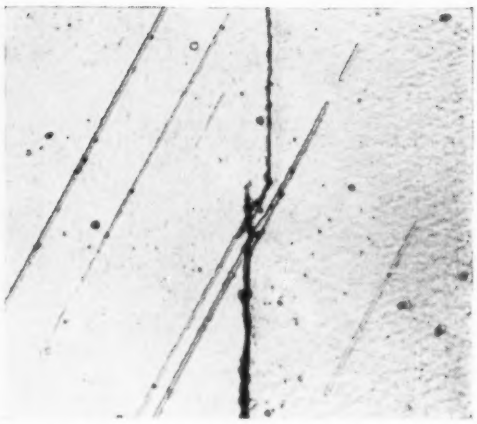
6a *and* **b** *Sections cut parallel to face 1, crystal A. Steps are formed at the intersection of lamellae with the cleavage surface. Note the internal crack running on beyond the step in (b)*

Neumann lamellae. Figure 7 also shows an internal crack parallel with the main fracture crossing one of the same set of lamellae forming a discontinuity and step parallel with the twin interface, but Fig.8 shows, at another spot of the same crack, that a crack has formed in the twin itself which might be due to cleavage within the twin. Other examples of such fractures were observed and Berry[10,16] reported similar cracks which he considered might be attributable to cleavage within the twinned metal. Owing to their small dimensions, it is not possible to measure the inclination of these cracks nor to identify the plane. It is clear, however, that where the fracture is diverted in this way, the inclinations of the steps to the fracture plane would differ from those which follow the twin interfaces.

Crystal *B* was cut so that the plane of section was at right angles to the block system on the surface. One of these sections is shown in Fig.9. The mean of a number of measurements on both sets of striations intersecting the surface at 90°, was 36–38°.

Thus, there is ample evidence from all sources, that the major block pattern found on the fracture surface of iron crystals, which have parted by cleavage parallel to the {100} planes, is due primarily to the previously formed Neumann lamellae which have converted the crystal into a group of nearly parallel blocks.

Some of the steps were sufficiently large for microscopical examination of the surfaces to be made. This was accomplished by turning the specimen until the plane of the step was normal to the objective and incident light. Most of them showed a number of striations, some resembling Neumann lamellae, others slip bands. Some of the wide marks are probably caused by the intersection of crossing twins. In Fig.10, planes of indices (112) and $(1\bar{1}2)$ for example intersect along the $[\bar{2}0\bar{1}]$ direction which is inclined at an angle of 50° to the fracture plane and this angle



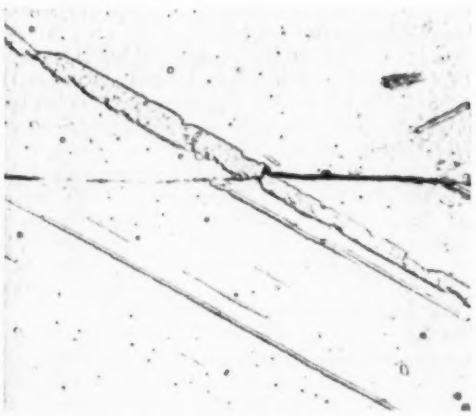
7 *Internal crack forms a step by following twin interface* × 800

has been recorded on some faces. At present it is not possible to give an explanation of the fine markings. They are also prominent on some electron diffraction replicas to be described later. It should be remembered however, that the outlines of Neumann lamellae are often irregular and that when separation occurs by shear parallel with the interfaces, as it must in the parting of the crystal and the formation of steps, these irregularities will show as striations on the surfaces of the lamellae.

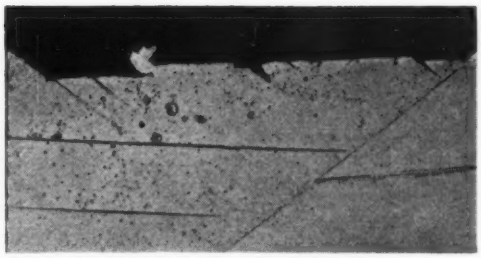
Closely related to the major markings are those referred to in category (*c*), p.134. Figure 2 shows a large number of these regular marks resembling etch pits, which are roughly triangular in shape. The base of the triangle was always found to be parallel with one of the block systems and sometimes an area was found, e.g. Fig.11, where two sets at right-angles corresponded clearly with the two major directions of the rectangular blocks. Hence, it was deduced that there was some relation between the two types of surface markings and a tentative explanation is proposed in the summary when further information on the structure of these markings has been given.

RESULTS OBTAINED WITH A SCANNING ELECTRON MICROSCOPE

The electron microscope has been used in two ways



8 *Internal crack crosses and fractures wide twin lamella* × 800



9 *Section through crystal B at right angles to one set of lamellae* ×500

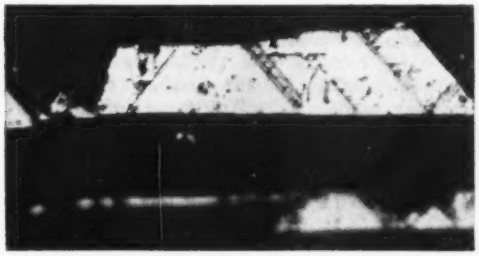
in order to investigate the small surface markings on cleavage fractures of α-iron.

In 1952, Dr A. Revere, Washington DC, made replicas from the cleavage face of crystal 9 of the paper by Tipper and Hall,[12] which showed a pronounced block formation. Figures 12 and 13 are examples of the structures obtained and these may be compared with Fig.10 which was obtained in an endeavour to confirm the structures on the replicas, and also with the photographs recently published by Crussard and his associates.[8] The structures shown by Dr Revere's replicas may sometimes be attributed to steps and twins constituting the block system, but there are also smaller ridges or depressions showing striations resembling those in the larger structure. In some areas there are much smaller projections and pits, the last being clearly seen on a particularly smooth part of the fracture face in Fig.13.

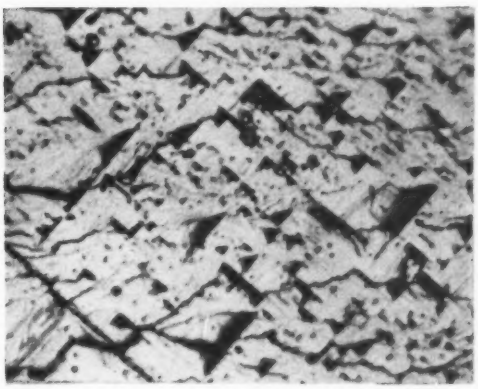
Recent improvements in the scanning electron microscope[3] made it possible to obtain photographs directly from the cleavage faces of some of the crystals described in the investigations carried out.

Preliminary experiments showed the advantages likely to accrue from this method. Figure 14*a* and *b* are optical and electron micrographs of the same field in a region of the fracture surface where the structure was chiefly of the 'river pattern' type. The difference in appearance is partly due to the fact that the angle of incidence is normal to the surface in the optical photograph and at 45° to it in the electron micrograph. This is made possible by the greater depth of focus. Experiment showed that if the incident beam was normal to the surface there was little advantage to be gained over a high-power optical photograph. With the beam at an angle, however, the structure stood up clearly in relief, and fine lines in the optical photograph appeared as steps in that of the electron micrograph.

The surfaces chosen for investigation were the two fractures shown in Fig.3*a* and *b*, which are mirror



10 *Surface of 'step', crystal B, normal illumination* ×500



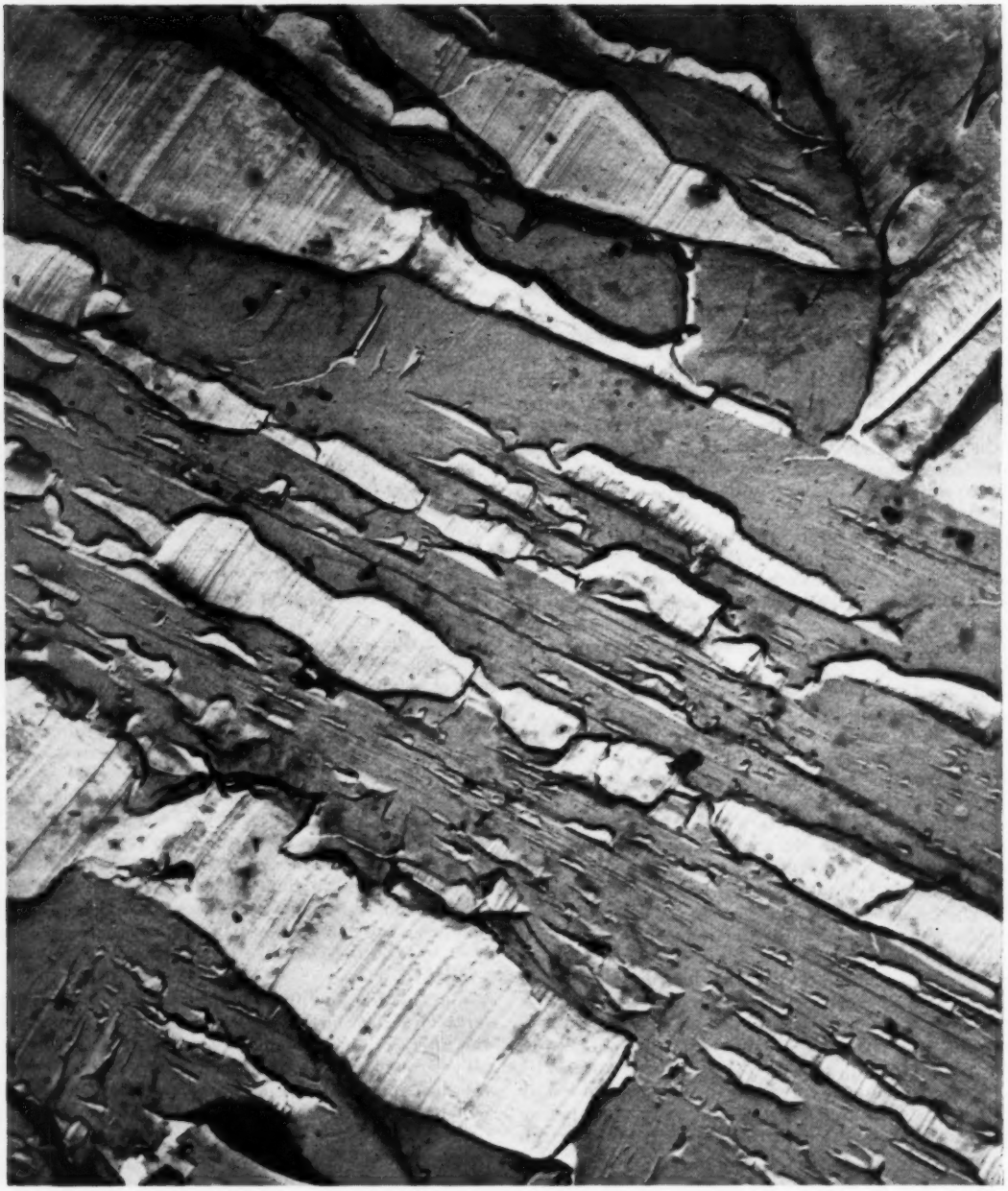
11 *Small surface markings following both directions of block system* ×800

images of one another. The regions of special interest were those near the centre of the cross made by the intersecting Neumann lamellae. Photomicrographs showed the presence of small surface irregularities, which corresponded exactly in position on both surfaces. These are shown in the top two photographs of Fig.15. Photographs obtained with the electron microscope are shown below. It is clear from these photographs that some of the irregularities are projecting flakes matched by pits on the opposite cleavage face. Both pits and protuberances were all aligned to one or other of the large steps of the block system. It is reasonable to conclude, therefore, that they are also related to the crystal structure and to the Neumann lamellae.

By taking photographs with the electron beam scanning the specimen from two directions at 90°, a special holder being constructed to rotate the specimen about a vertical axis, Wells[3] was able to calculate the angle which the flakes shown in Fig.15 made with the (001) plane. The large flake consisted of two zones inclined at 29° and 20° ± 5° respectively.

SUMMARY

While there is now little doubt that the large blocks on the fracture surfaces of these crystals are caused by the intersection of Neumann lamellae, it is still necessary to consider what happens when a propagating fracture meets a lamella in its path. The striations which constitute the 'river pattern' are a good guide to the direction of fracture propagation. A study of photographs, in particular Figs.1–3, reveals that the lamellae cause little disturbance in the pattern while they are parallel with the direction of propagation, but arrest the fracture when they are encountered at right-angles to this direction, often, when they are traversed, leading to re-initiation and propagation in a different direction. Note in particular, the centre block of Fig.1, and the centre of the cross in Fig.3*a* and *b*. Re-initiation is also on a different plane, forming the step already noted. The lamella, being of a different orientation to the main crystal, acts in every respect as a crystal of a different orientation in the way of a propagating fracture. An example of an included crystal is shown in Fig.16, and it will be seen that this crystal has deformed before fracture so that it projects above the cleavage surface. Similarly, it



12 *Electron microscope replica of crystal. Cleavage surface showing striations on flakes and steps* × 10 000

may be postulated that the Neumann lamellae deform before fracture on planes parallel with their slip planes, unless they are suitably disposed for cleavage. One of the possible slip planes is the composition plane of the twin, common to both the main crystal and the twin. If shear occurs on this plane, an inclined step will result, such as that found along the sides of the rectangular blocks.

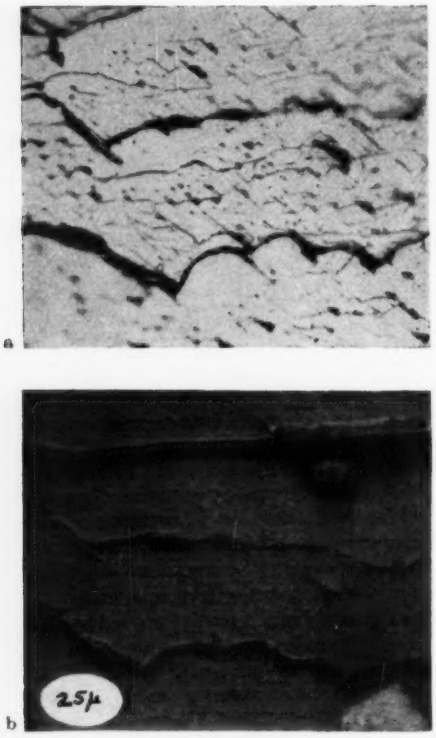
Not all lamellae which appear on a polished surface contribute to the block system. The number far exceeds the number of blocks, and many do not reach the fracture surface. It is the wide and most extensive bands which coincide with the large steps or blocks. These are probably the first formed, those forming later being smaller, interrupted, and often irregular, due to the distortion caused by the initial group. The smaller ones may form blocks within the large block and interrupt the fracture to a lesser extent, but nevertheless give rise to a discontinuity, such as those shown in Fig.5. It is probable that a further number are initiated by the fracture itself as suggested by Tipper and Sullivan.[7] Some of the very short ones

13 *Electron microscope replica of crystal. Cleavage surface showing pits* × 10000

near the crack, confined to one surface, may be due to this cause (Fig.17).

The close connection between cleavage in b c c metals and twin formation led Bruckner[13] to suggest that cleavage originates at the twin interfaces, although service fractures, consisting chiefly of cleavage may show no Neumann lamellae. Cahn,[14] however, has shown how cleavage cracks can arise at the intersection of Neumann lamellae in molybdenum crystals. When twins formed there were cracks; without twins the crystals deformed without cracking. Bell and Cahn[17] have also confirmed the importance of twin formation in initiating cleavage fractures in zinc.

There is evidence, on the other hand, that the lamellae act as crack arresters, in much the same way as a tough, ductile steel plate joined to a brittle one may temporarily arrest fracture propagation by itself deforming plastically. If the lamella is restrained from deforming, a new crack may be initiated at a discontinuity such as that of its opposite boundary, and when this has occurred, the lamella is free to deform and fracture, its two ends projecting above the



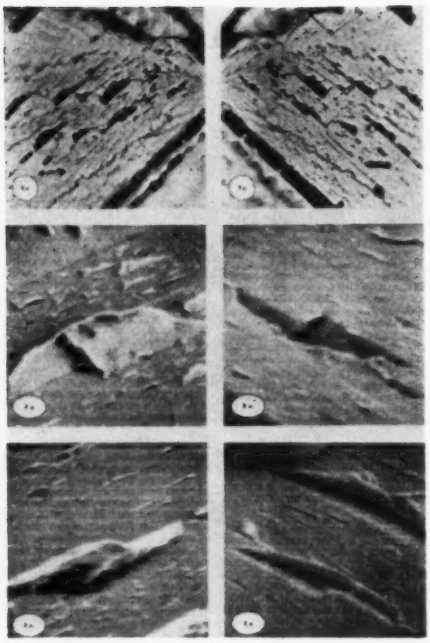
14 *(a) Optical photograph (×500), and (b) scanning electron micrograph of (a), angle of incidence 45°*

cleavage surface, giving rise to the fins or tongues shown in Figs.12, 15.

As demonstrated in Figs.6 and 7, cracks sometimes follow the twin boundaries and this might readily occur if the fracture path passed close to the end of a twin. If the fracture followed round the end, rather than traversing the twin, a projection on one face would coincide with a depression on the other. The existence of both projecting flakes and pits has been demonstrated (Figs.15 and 17).

The shape of the flakes and pits calls for comment. The tips of the flakes are rounded and slightly irregular. In the first place, some distortion may be expected, either due to accidental damage, or to plastic deformation within the lamella. Secondly, the ends of the lamella are tapered, so that should the fracture follow the twin boundary the angle which the projecting end makes with the main crystal is likely to deviate from that of the twin as a whole. Assuming that the projections are the ends of twin lamellae as suggested, if there were no distortion, the angle between the surface of the projection and the fracture surface should be approximately 36°. The angle calculated by Dr Wells, for one flake only, was $20°–29° \pm 5°$.

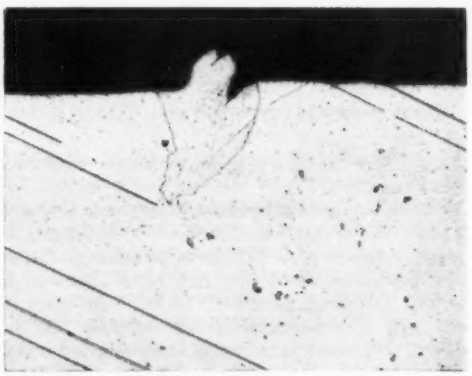
The absence of pits and projections on some areas of the cleavage surface is in accordance with the absence of Neumann lamellae. What is more difficult to explain is the very large number of very small flakes, shown in Fig.15. They still maintain a regular alignment parallel with the {112} planes, so that it is reasonable to conclude that they have essentially the same geometrical structure as the larger ones. Slag



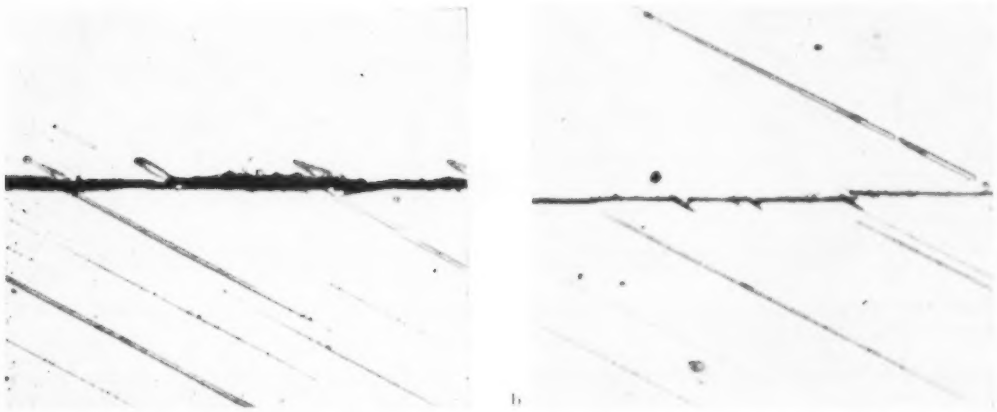
15 *Both fracture surfaces of crystal A. Optical and electron micrographs showing flakes and pits. Angle of incidence 45°*

inclusions have not been found to give rise to geometrical surface markings and the 'river pattern' markings still maintain smooth outlines, essentially non-crystallographic in character, merging into those of geometrical form.

Finally, attention is drawn to the fact that, even in the cleavage of single crystals, there is evidence of prior plastic deformation, by which the crystal is subdivided into a system of nearly parallel blocks, thereby causing a reduction in effective grain size. The discontinuous nature of fracture propagation, which is so characteristic of polycrystalline material and even structures, where details introduce stress concentrations, is also a characteristic of fracture of crystals by cleavage.[15] Many of the observations also apply to the fractures of other metals and minerals, a discussion of which has been omitted in the interest of brevity.



16 *Distorted small crystal in way of cleavage fracture* ×150



17 *(a) Short lamellae near internal crack, (b) another region of internal crack shows pits following the same direction of the lamellae* ×500

ACKNOWLEDGMENTS

The observations recorded in the foregoing have been made over a long period and are the result of co-operation between several people.

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The influence of minor elements on the isothermal embrittlement of steels

W. Steven, Ph.D., F.I.M., and K. Balajiva, Ph.D., F.I.M.

IT HAS BEEN KNOWN for some time that the embrittlement of hardened-and-tempered low-alloy steels, which occurs as a result of heating at temperatures in the range 300–600°C, or of slow cooling through this range from tempering temperatures, raises the impact-transition-temperature range.[1] It is also well known that impurities such as phosphorus and tin play an important part in this type of embrittlement.[2–4] The effects of other factors which influence the temper embrittlement of steels have been reviewed by Hollomon[5] and by Woodfine.[6]

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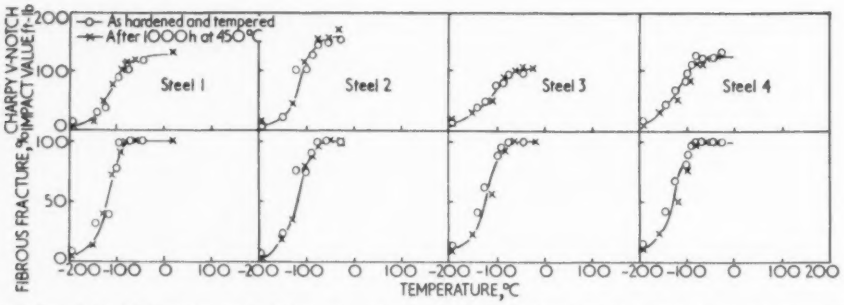
SYNOPSIS

Tests on steels of controlled purity show that isothermal embrittlement is due to the presence of traces of impurities such as phosphorus, arsenic, antimony, and tin and not to the presence of carbon and the normal alloying elements, nickel, chromium, or molybdenum. 1637

In the first stage of work under the present programme of research, the results of which have been reported elsewhere,[7] it was shown that high-purity steels are not susceptible to isothermal embrittlement. The present paper is concerned with a further study of



1 *Impact properties of the high-purity steels before and after re-heating at 450°C. Steels 1 and 3 powder-made, steels 2 and 4 vacuum-melted*

the immunity to embrittlement shown by high-purity steels and with the effects, on this immunity, of the presence of controlled amounts of various elements. In the final section of the paper some attention is given to the fracture habits of some of the steels.

EXPERIMENTAL PROCEDURE

High-purity steels of nominal composition 0·3%C, 3·0%Ni, 0·75%Cr, in some cases containing also 0·5%Mo, were prepared by powder metallurgy (steels 1 and 3), or by vacuum-melting (steels 2 and 4). Both methods proved satisfactory, but the vacuum-melting method was preferred in view of its simplicity and was therefore adopted for preparation of the steels containing additions of other elements which might cause isothermal embrittlement, namely manganese, silicon, phosphorus, antimony, arsenic, tin, bismuth, cobalt, copper, germanium, gallium, zirconium, and nitrogen (steels 5–47). The compositions of all the steels are given in Table I.

Details of the preparation of the steels are given in Appendix I, and the methods of analysis adopted are outlined in Appendix II.

The steels were forged and rolled to $\frac{5}{8}$-in. dia. bar and heat-treated as blanks roughly 5 in. long. Each steel was fully hardened, tempered, and water-quenched from the tempering temperature. As-quenched grain sizes were in the range 7–8 ASTM.

The embrittling treatment employed consisted in re-heating the hardened-and-tempered steels at 450°C for 168 or 1000 h and water-quenching. The impact-transition range of each steel, before and after exposure at 450°C, was determined, using standard Charpy V-notch specimens (10 mm × 10 mm × 60 mm). Degree of embrittlement was assessed by the shift of the impact-transition range.

Transition temperature was assessed by two criteria: the temperature at which the fracture was 50% fibrous, and the lowest temperature at which the fracture was wholly fibrous. The results are presented in Table II.

IMPACT PROPERTIES OF THE HIGH-PURITY STEELS

The high-purity steels (nos. 1–4, Table I) were first oil-quenched from 850°C and tempered at 650°C. It was found that steel 4 contained some undissolved carbide, along the prior austenite boundaries, and consequently had a comparatively high impact-transition-temperature range. The austenitizing temperature for this steel was, therefore, raised to 870°C.

The impact-transition curves for the four steels, before and after re-heating at 450°C for 1000 h, are shown in Fig.1. Neither the impact-transition ranges nor the maximum impact values of the molybdenum-free steels (nos. 1 and 2) were affected by the isothermal treatments. The maximum impact values of the molybdenum-bearing steels (nos.3 and 4) were also unaffected, as were the upper and lower limits of the impact-transition range. At temperatures within the transition range it was possible to draw two curves through the experimental points, which would suggest that a slight amount of embrittlement had occurred during re-heating at 450°C, but it is considered that the experimental accuracy and reproducibility of the data would not fully justify this conclusion.

The prolonged heating at 450°C did not significantly alter the hardness values of any of the four high-purity steels (Table II).

The maximum impact values of the vacuum-melted steels were higher than those of their powder-made counterparts (Fig.1). The reasons for this difference were not fully explored, but microscopical examination of specimens of the powder-made steels revealed no evidence of porosity or heterogeneity.

Susceptibility to embrittlement during slow cooling from a tempering treatment was also assessed on one of the steels (no.2). Bars of the steel were oil-quenched from 850°C and tempered at 625°C for 2 h: half of the bars were water-quenched and the rest were allowed to cool slowly to room temperature (at the rate of about 13°C/h, from 600° to 300°C). If embrittlement did occur, it was to a degree only within the limits of experimental error (Fig.2).

The results obtained from these high-purity steels suggest that the major alloying elements, carbon, nickel, chromium, and molybdenum, are not primarily responsible for the temper-embrittlement of steels. Since the vacuum-melted steels, although relatively pure, contained 0·06%Al, which was probably derived from the material used to patch the magnesia furnace lining, it may reasonably be concluded that aluminium contents up to at least this level do not induce susceptibility to isothermal embrittlement.

THE INFLUENCE OF IMPURITIES ON ISOTHERMAL EMBRITTLEMENT

The nickel–chromium steels containing controlled additions of impurities (nos.5–27, Table I), were oil-quenched from 850°C and tempered at 600°C, whilst the nickel–chromium–molybdenum steels (nos.28–47, Table I) were oil-quenched from 870°C and tempered

TABLE I Compositions of the steels

Steel	Analysis, wt-% C	Ni	Cr	Mo	Si	Mn	S	P	Al	V	Cu	As	Sn	Pb	Ti	Mg	N	O	Other elements
1*	0·29	3·01	0·75	< 0·1	< 0·1	< 0·1	0·001	0·003	0·015	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·007	0·023	...
2	0·33	3·27	0·75	< 0·1	< 0·1	< 0·1	0·001	0·003	0·06	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	< 0·0005	...
3*	0·32	2·98	0·77	0·46	< 0·1	< 0·1	0·001	0·003	0·015	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·500	0·018	...
4	0·35	3·20	0·76	0·51	< 0·1	< 0·1	0·002	0·003	0·06	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·0005	0·0008	...
5	0·25	2·78	0·72	< 0·1	< 0·1	< 0·1	0·002	0·005	0·04	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·0005	0·001	...
6	0·28	2·75	0·74	< 0·1	< 0·1	< 0·1	0·003	0·008	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·0005	0·002	...
7	0·30	3·20	0·69	< 0·1	< 0·1	< 0·1	0·004	0·040	0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
8	0·32	3·00	0·70	< 0·1	< 0·1	< 0·1	0·001	0·003	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·001	Sb 0·001
9	0·27	3·10	0·58	< 0·1	< 0·1	< 0·1	0·001	0·003	0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	Sb 0·05
10	0·23	2·78	0·79	< 0·1	< 0·1	< 0·1	0·003	0·003	0·03	< 0·01	< 0·01	0·11	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
11	0·23	2·78	0·79	< 0·1	< 0·1	< 0·1	0·003	0·003	0·03	< 0·01	< 0·01	0·23	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
12	0·31	2·90	0·78	< 0·1	< 0·1	< 0·1	0·001	0·003	0·01	< 0·01	< 0·01	< 0·01	0·034	< 0·002	< 0·01	< 0·01	< 0·0005	0·001	...
13	0·31	2·90	0·78	< 0·1	< 0·1	< 0·1	0·001	0·003	0·01	< 0·01	< 0·01	< 0·01	0·068	< 0·002	< 0·01	< 0·01	< 0·0005	0·001	...
14	0·32	3·10	0·74	< 0·1	< 0·1	< 0·1	0·002	0·001	0·02	< 0·01	< 0·01	< 0·01	0·11	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
15	0·27	3·05	0·79	< 0·1	< 0·1	0·70	0·002	0·002	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·003	...
16	0·25	3·00	0·78	< 0·1	< 0·1	0·73	0·003	0·002	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·0008	0·002	...
17	0·27	3·05	0·79	< 0·1	< 0·1	1·50	0·002	0·002	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·003	...
18	0·26	3·30	0·78	< 0·1	0·74	< 0·1	0·002	0·003	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·003	...
19	0·34	3·20	0·71	< 0·1	< 0·1	< 0·1	0·002	0·001	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·0005	0·002	Bi 0·002
20	0·30	3·25	0·76	< 0·1	< 0·1	< 0·1	0·003	0·004	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	Co 0·05
21	0·30	2·90	0·75	< 0·1	< 0·1	< 0·1	0·002	0·004	0·04	< 0·01	0·066	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	...
22	0·30	2·90	0·75	< 0·1	< 0·1	< 0·1	0·002	0·004	0·04	< 0·01	0·17	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	...
23	0·31	3·20	0·81	< 0·1	< 0·1	< 0·1	0·002	0·002	0·01	< 0·01	0·22	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	...
24	0·22	3·20	0·74	< 0·1	< 0·1	< 0·1	0·003	0·002	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	Ge 0·01
25	0·23	3·10	0·77	< 0·1	< 0·1	< 0·1	0·003	0·002	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	Ga 0·01
26	0·28	3·00	0·88	< 0·1	< 0·1	< 0·1	0·003	0·003	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	Zr 0·05
27	0·29	3·05	0·78	< 0·1	< 0·1	< 0·1	0·002	0·003	0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·019	0·003	...
28	0·30	3·00	0·73	0·49	< 0·1	< 0·1	0·004	0·005	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·001	...
29	0·31	2·70	0·74	0·49	< 0·1	< 0·1	0·003	0·011	0·04	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
30	0·35	3·15	0·71	0·69	< 0·1	< 0·1	0·002	0·016	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
31	0·33	3·35	0·72	0·55	< 0·1	< 0·1	0·003	0·033	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
32	0·26	3·10	0·74	0·50	< 0·1	< 0·1	0·003	0·002	0·03	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·0005	0·002	Sb 0·008
33	0·26	3·15	0·81	0·49	< 0·1	< 0·1	0·001	0·003	0·02	< 0·01	< 0·01	0·062	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
34	0·31	3·20	0·70	0·48	< 0·1	< 0·1	0·004	0·002	0·03	< 0·01	< 0·01	0·10	< 0·01	< 0·002	< 0·01	< 0·01	0·0005	0·002	...
35	0·26	3·15	0·81	0·49	< 0·1	< 0·1	0·001	0·003	0·02	< 0·01	< 0·01	0·135	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
36	0·23	2·85	0·75	0·49	< 0·1	< 0·1	0·001	0·003	0·04	< 0·01	< 0·01	< 0·01	0·035	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
37	0·23	2·85	0·75	0·49	< 0·1	< 0·1	0·001	0·003	0·04	< 0·01	< 0·01	< 0·01	0·068	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
38	0·30	2·90	0·74	0·48	< 0·1	< 0·1	0·003	0·001	0·02	< 0·01	< 0·01	< 0·01	0·08	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
39	0·27	2·93	0·78	0·51	< 0·1	0·67	0·004	0·003	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
40	0·26	3·00	0·81	0·49	0·69	< 0·1	0·002	0·003	0·05	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	...
41	0·24	3·15	0·79	0·47	< 0·1	< 0·1	0·002	0·002	0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	Co 0·10
42	0·25	2·83	0·75	0·50	< 0·1	< 0·1	0·001	0·003	0·06	< 0·01	0·07	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	...
43	0·25	2·83	0·75	0·50	< 0·1	< 0·1	0·001	0·003	0·06	< 0·01	0·18	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	...
44	0·31	3·10	0·76	0·47	< 0·1	< 0·1	0·003	0·003	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	Ge 0·01
45	0·25	3·20	0·77	0·46	< 0·1	< 0·1	0·004	0·003	0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	...	...	Ga 0·01
46	0·29	3·00	0·78	0·45	< 0·1	< 0·1	0·002	0·003	0·02	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	< 0·0005	0·002	Zr 0·05
47	0·24	2·95	0·65	0·46	< 0·1	< 0·1	0·002	0·003	0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·002	< 0·01	< 0·01	0·006	0·005	...

Except where otherwise stated, the following elements were not detected: Sb, Bi, Co, Ge, Ga, Zr.
The following elements were not detected in any of the steels: W, Zn, B, Nb, Te, Th.
* These steels were prepared by powder-metallurgical methods, all others were prepared by vacuum-melting.

TABLE II Isothermal embrittlement at 450°C, summarized data

Steel	Type	Added element, %	Hardness, VPN		Transition temperature, °C						Maximum impact value, ft-lb			Shift of transition temperature in 1 000 h	
					50% fibrous criterion			100% fibrous criterion							
			Initial	After 1 000 h	Initial	After 168 h	After 1 000 h	Initial	After 168 h	After 1 000 h	Initial	After 168 h	After 1 000 h	50% fibrous	100% fibrous
2	Ni-Cr	nil	252	247	−126	−126	−120	−60	−60	−60	148	150	152	6	0
5	,,	P 0·005	243	244	−160	−130	−112	−105	−80	−60	176	172	170	48	45
6	,,	P 0·008	256	250	−150	−96	−72	−110	−50	−20	156	160	150	78	90
7	,,	P 0·04	279	277	−92	−10	0	−20	+70	+90	112	108	118	92	110
8	,,	Sb 0·001	259	254	−144	−88	−40	−90	+40	+120	145	100	80	104	210
9	,,	Sb 0·05	257	258*	...	...	...	c. +40	> 300	...	46	...	...	...	> 300*
10	,,	As 0·11	244	238	−164	−114	−96	−110	−50	−10	165	174	186	68	100
11	,,	As 0·23	245	241	−144	−70	−44	−100	+10	+80	162	170	180	100	180
12	,,	Sn 0·034	261	257	−100	−48	−6	−30	+50	+110	138	138	139	94	140
13	,,	Sn 0·068	264	263	−66	18	+10	+30	+80	+140	120	112	120	76	110
14	,,	Sn 0·11	278	278	−64	−30	−30	+10	+60	+120	94	68	76	34	110
15	,,	Mn 0·70	257	255	−130	−72	−52	−70	0	+10	129	120	122	78	80
16	,,	Mn 0·73	264	253	−132	−64	−26	−80	−20	+30	130	118	122	106	110
17	,,	Mn 1·50	266	260	−76	+86	+112	−10	+150	+170	116	117	108	188	180
18	,,	Si 0·74	271	273	−108	−102	−94	−80	−50	−40	94	98	98	14	40
19	,,	Bi 0·002	271	269	−116	−106	−100	−60	−70	−60	54	43	48	16	0
20	,,	Co 0·05	263	257	−128	−132	−126	−85	−85	−85	77	68	73	2	0
21	,,	Cu 0·066	252	250	−142	−138	−142	−80	−80	−80	153	166	160	0	0
22	,,	Cu 0·17	253	253	−140	−134	−130	−80	−80	−80	160	164	166	10	0
23	,,	Cu 0·22	236	227	−124	−132	−124	−50	−50	−50	136	138	146	0	0
24	,,	Ge 0·01	237	236	−162	−158	−158	−110	−104	−110	174	174	180	4	0
25	,,	Ga 0·01	242	237	−168	−168	−158	−120	−120	−115	168	160	157	10	5
26	,,	Zr 0·05	251	245	−110	−108	−100	−10	−10	−10	138	130	131	10	0
27	,,	N 0·019	249	248	−86	−86	−86	−20	−20	−20	118	118	120	0	0
4	Ni-Cr-Mo	nil	288	285	−138	...	−122	−70	...	−70	120	...	118	16	0
28	,,	P 0·005	273	269	−100	−100	−110	−50	−50	−20	122	110	124	−10	30
29	,,	P 0·011	274	273	−92	−80	−94	−10	−10	+20	122	106	104	−2	30
30	,,	P 0·016	275	276	−110	−100	−80	−10	+10	+30	116	116	104	30	40
31	,,	P 0·033	279	274	−130	−96	−88	−40	−30	0	122	112	118	42	40
32	,,	Sb 0·008	280	281	−152	−122	−90	−100	−60	+20	134	116	70	62	120
33	,,	As 0·062	260	253	−168	−168	−150	−110	−110	−100	166	156	156	18	10
34	,,	As 0·10	271	271	−136	−130	−130	−80	−80	−80	140	132	140	6	0
35	,,	As 0·135	257	263	−166	−150	−148	−120	−100	−90	158	154	160	18	30
36	,,	Sn 0·035	250	255	−154	−142	−134	−120	−80	−80	170	187	178	20	40
37	,,	Sn 0·068	251	257	−148	−130	−132	−90	−60	−60	188	168	157	16	30
38	,,	Sn 0·08	286	293	−156	−130	−130	−100	−80	−70	120	98	100	26	30
39	,,	Mn 0·66	270	276	−136	−134	−128	−90	−85	−80	116	114	114	8	10
40	,,	Si 0·69	272	278	−136	−126	−108	−66	−30	−20	132	132	132	28	40
41	,,	Co 0·10	249	248	−148	−150	−138	−80	−80	−80	150	150	148	10	0
42	,,	Cu 0·07	257	259	−146	−142	−134	−60	−60	−60	158	166	168	12	0
43	,,	Cu 0·18	259	259	−148	−140	−134	−60	−60	−60	170	170	177	14	0
44	,,	Ge 0·01	258	259	−138	−130	−130	−30	−40	−30	142	143	148	8	0
45	,,	Ga 0·01	272	268	−160	−152	−136	−80	−80	−80	120	128	113	24	0
46	,,	Zr 0·05	272	262	−96	−94	−98	−10	0	−10	126	130	136	−2	0
47	,,	N 0·006	244	254	−146	−148	−138	−90	−90	−80	123	137	134	8	10

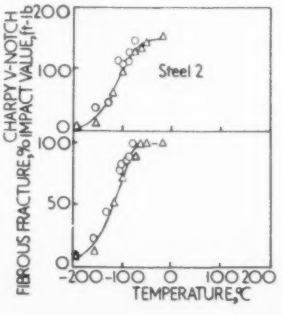
* After 168 h

at 670°C. All the bars were water-quenched after tempering.

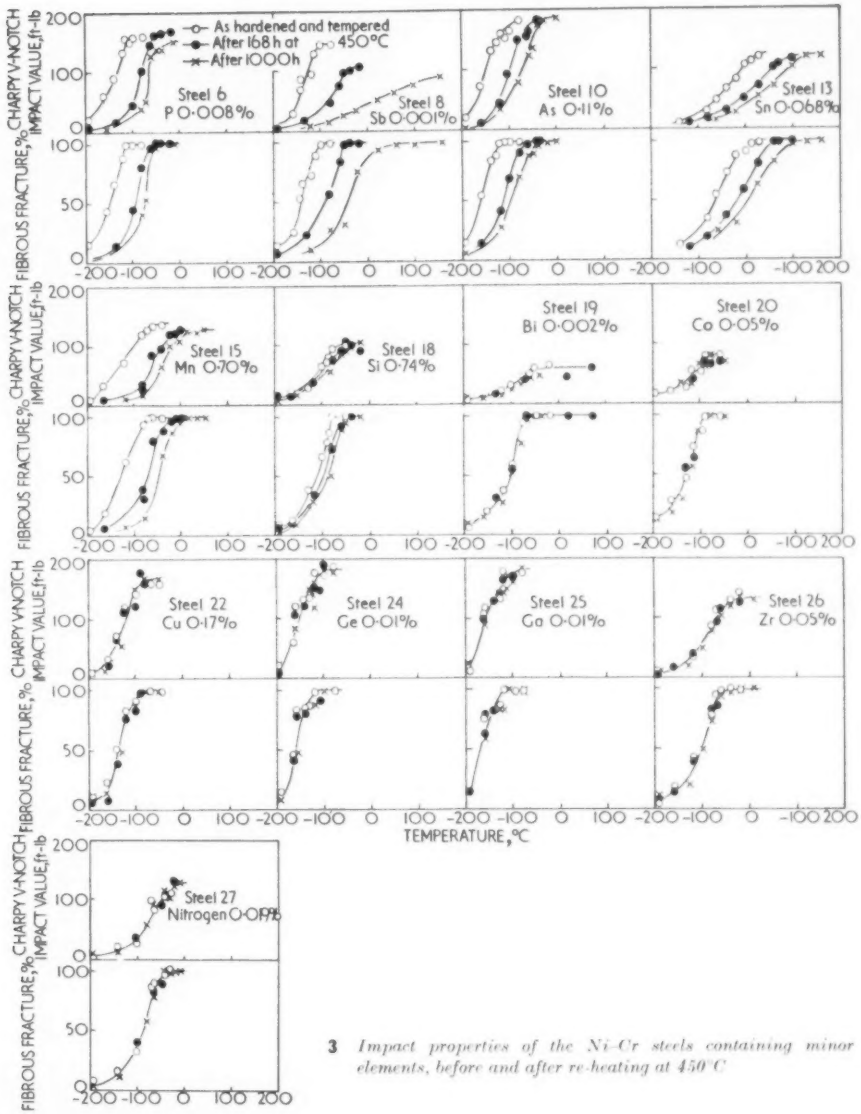
By either criterion of impact-transition temperature (50% or 100% fibrous fracture) the steels containing bismuth, cobalt, copper, germanium, gallium, zirconium, or nitrogen (nos.19–27, Table II) showed no significant isothermal embrittlement. By comparison with the corresponding values for the high-purity steel (no.2), the maximum impact values for steels nos.19 and 20, containing bismuth and cobalt, were low, and the transition temperatures for steels nos.26 and 27, containing zirconium and nitrogen, were high. These results might be interpreted as indicating that some rapid embrittlement had occurred during tempering at 600°C, due to the presence of bismuth, cobalt, zirconium, or nitrogen, but such suspicion was not confirmed by the examination of impact fractures, as will be shown later.

The presence of phosphorus, antimony, arsenic, tin, manganese, or silicon was found to induce embrittlement during re-heating at 450°C: a selection of typical results is shown in Fig.3. In nearly all cases the major part of the embrittlement occurred in less than 168 h. Antimony was the most potent element; silicon had the least effect.

The rise in the transition-temperature range of the antimony-containing steel was accompanied by a fall in the impact value for the steel at temperatures above the transition ranges. An increase in the content of each embrittling element caused increased shift of the transition temperature after 1 000 h at 450°C (Table II). The tin-containing steels showed an exception to this trend, but the transition temperatures of steels 13 and 14 were already higher than that of steel 12 before the isothermal treatment. The significance attached to this observation will be indicated later.



2 *Impact properties of the high-purity steels as water-quenched and as slowly-cooled after tempering*



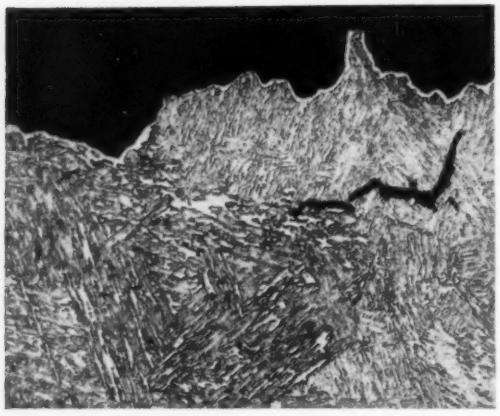
3 *Impact properties of the Ni–Cr steels containing minor elements, before and after re-heating at 450°C*

TABLE III Brittle fractures of the nickel–chromium steels before and after re-heating at 450°C

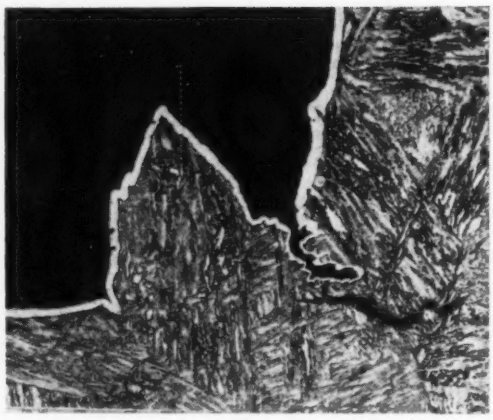
Steel	Elements added, %	Type of brittle fracture: Hardened-and-tempered condition	Type of brittle fracture: After 168 h at 450°C
2	nil	Cleavage	Cleavage
19	Bi 0·002	Cleavage	Cleavage
26	Zr 0·05	Cleavage	Cleavage
27	N 0·019	Cleavage	Cleavage
7	P 0·04	Cleavage + 40% intergranular	Intergranular
8	Sb 0·001	Cleavage + 10% intergranular	Cleavage + 30% intergranular
11	As 0·23	Cleavage + 60% intergranular	Mainly intergranular
13	Sn 0·068	Intergranular	Intergranular
15	Mn 0·70	Cleavage + 30% intergranular	Intergranular
18	Si 0·74	Cleavage + 50% intergranular	Mainly intergranular

Steels 5, 6, 10, 11, 24, and 25, had lower transition temperatures and higher maximum impact values than the corresponding high-purity steel (no.2, Table II): it is believed that the difference is due to their lower carbon contents (Table I).

In general, as the amount of each embrittling element was increased, the transition temperatures of the quenched-and-tempered steels before re-heating at 450°C rose, and the maximum impact values noticeably fell. In this respect the arsenic-containing steels (nos.10 and 11) were exceptional. These observations suggest that some embrittlement had occurred during the tempering treatment. Such embrittlement would explain the results for the tin-containing steels and embrittlement at the tempering temperature had apparently masked the effects of the lower carbon contents of the antimony-, manganese-, and silicon-containing steels.



4 *Cleavage brittle fracture of the high-purity steel 2, after reheating at 450°C for 168 h. Impact value at −196°C 13 ft-lb. Etched in picral containing 2% nitric acid* ×300



5 *Mixed cleavage and intergranular brittle fractures of steel 11, as hardened-and-tempered. Impact value at −149°C 16 ft-lb. Etched in picral containing 2% nitric acid* ×300

The impact-test results for the nickel–chromium–molybdenum steels (nos.28–47) presented in the lower part of Table II show that the presence of 0·5%Mo markedly reduced, but did not eliminate, the embrittlement caused by phosphorus, antimony, arsenic, tin, and manganese. Even in the presence of molybdenum the effect of antimony was still appreciable. Molybdenum did not appear to influence the degree to which silicon induced isothermal embrittlement, but the effect of silicon was, in any case, small.

FRACTURES

Microexamination of specimens of the various heat-treated steels, etched in an ethereal solution of picric acid containing cetyl tri-methyl ammonium bromide (CTAB), revealed preferential grain-boundary etching on some of the steels, but for steels which had been shown by impact test to be susceptible to embrittlement, no consistent difference could be observed between the etching characteristics of the specimens before and after re-heating at 450°C. Examination of the fractures of some of the broken impact specimens suggested that brittle fracture which occurred in the high-purity steels was transgranular, and that in the steels containing embrittling elements was intergranular. The grain sizes of the steels were, however, too fine for such conclusions to be more than tentative.

To study this aspect more closely, an examination was made of the fractures of nickel–chromium steels containing phosphorus, antimony, arsenic, tin, manganese, silicon, bismuth, zirconium, and nitrogen, in which a large grain size (roughly 3 ASTM) had been deliberately developed by austenitizing at 1000°C for 1 h. The bars were oil-quenched, tempered at 600°C, and water-quenched. Half of the bars were then re-heated at 450°C for 168 h and water-quenched. The impact specimens were broken at temperatures in the range −150° to −196°C.

The results, shown in Table III, indicate that the specimens could be divided, according to the type of fracture, into two groups:

(i) those which, both before and after isothermal treatment, gave essentially transgranular or cleavage brittle fracture, i.e. the high-purity steel and the steels containing bismuth, zirconium, and nitrogen, which had been found by impact tests to be non-susceptible to isothermal embrittlement

(ii) the other steels containing embrittling elements, which gave a mixture of cleavage and intergranular fractures in the quenched-and-tempered condition and which, after isothermal treatment, showed increased tendency to fail in the intergranular manner along the prior austenite boundaries.

The fracture of the high-purity steel, after re-heating at 450°C, is shown in Fig.4: fractures of steels containing arsenic and tin, before isothermal treatment, are shown in Figs.5 and 6.

Examination had thus indicated that intergranular brittle fracture is closely associated with isothermal embrittlement, and the appearance, prior to the isothermal treatment, of intergranular brittle fracture in the susceptible steels provides further evidence that embrittlement occurred in some cases during tempering at 600°C.

DISCUSSION AND CONCLUSIONS

In the work described in this paper the effect of trace elements was assessed by re-heating only at 450°C.

6 *Intergranular brittle fracture of steel 13, as hardened-and-tempered, showing some internal cracks. Impact value at −150°C 7 ft-lb. Etched in picral containing 2% nitric acid* ×300

TABLE IV Composition of raw materials

Material	Impurities, wt-%		Material	Impurities, wt-%	
Carbonyl iron	Carbon	0·01	Electrolytic chromium	Boron	Not detected
	Nickel	0·19		Vanadium	„ „
	Oxygen	0·15		Manganese	0·005
	Sulphur	Not detected		Silicon	0·005
	Phosphorus	„ „		Magnesium	0·005
	Tin	„ „		Titanium	0·005
	Antimony	„ „		Aluminium	0·005
Nickel pellet	Iron	0·041		Copper	0·001
	Carbon	0·04		Lead	0·001
	Sulphur	0·001	Molybdenum	Silicon	>0·005
	Copper	0·003		Manganese	„
Electrolytic chromium	Nickel	0·02–0·03		Chromium	„
	Bismuth	Not detected		Antimony	Not detected
	Tin	„ „		Tin	„ „
	Antimony	„ „		Copper	„ „
	Arsenic	„ „		Cobalt	„ „
	Molybdenum	„ „		Germanium	„ „
				Gallium	„ „

Nevertheless, it is considered that the results obtained have established the qualitative effects of the impurities studied. Their quantitative effects will vary with the temperature at which the embrittlement is induced and may be dependent also on the microstructure of the steel and on the proportions of the normal alloying elements present. Moreover, this study was confined to assessing the separate effects of individual impurities and it cannot be assumed that the effect of two or more of the elements in combination will be simply additive. Within these limitations, the following conclusions appear to be justified:

1. A steel containing carbon, nickel, chromium, and molybdenum, but substantially free of trace elements, is not susceptible to embrittlement within 1000 h at 450°C.

2. The presence of phosphorus, antimony, arsenic, tin, manganese, or silicon promotes susceptibility to embrittlement at 450°C. The most potent of these elements is antimony. The presence of small percentages of bismuth, cobalt, copper, germanium, gallium, zirconium, or nitrogen, at least up to the levels studied in this investigation, does not induce susceptibility to embrittlement at 450°C.

3. Molybdenum retards, but does not prevent, development of embrittlement.

4. The brittle fractures of steels susceptible to embrittlement are substantially intergranular.

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APPENDIX I

PREPARATION OF HIGH-PURITY STEELS

By powder metallurgy

The component powders were mixed by ball milling for 2 h with Stellite balls, and were pressed at 15 tons/in², into (10 in. × 2 in. × 2 in.) compacts, each weighing about 10 lb. Carbon in excess of the amount finally required was incorporated in the powder mix as a means of reducing any oxides present, particularly Cr_2O_3. The compacts were sintered *in vacuo* for 4 h at 1200°C and were then forged to bars about 1¼ in. sq. These bars were then homogenized *in vacuo* at 1300°C for 4 h.

By vacuum melting

A charge consisting of carbonyl iron in the form of sintered cakes, graphite of spectrographic purity, and nickel pellets was melted under reduced pressure in a vacuum h f furnace. A rammed lining of pure fused magnesia, bonded with 1% boric acid, was used. Further additions of iron, chromium, molybdenum, and graphite were made, to produce a 25-lb melt of steel. The pressure was then reduced to 1 μ, and maintained at that level for a minimum of 10 min. The high-purity steel was then cast into a 3-in. dia. steel mould and allowed to solidify under vacuum.

For the steels containing additions of minor elements, argon was introduced into the furnace chamber to increase the pressure to 500 mm Hg. The minor elements, with the exception of phosphorus and nitrogen, were added in the elemental form. Phosphorus was introduced as iron phosphide; nitrogen was added as iron nitride, under nitrogen pressure slightly in excess of one atmosphere. All the steels except that containing nitrogen were cast under the argon atmosphere.

Some details of the raw materials used for both the powder-made steels and the vacuum-melted steels are given in Table IV.

APPENDIX II

ANALYTICAL METHODS

Determination of the non-metallic elements studied in these steels was carried out by chemical techniques; all other elements were determined spectrographically.

Carbon was estimated by the combustion/gravimetric procedures described in BS 1121, part II (1948). Sulphur also was determined by combustion. Phosphorus was determined by titration of the phospho-molybdate with caustic soda, and a few of the phosphorus contents were checked by a colorimetric technique based on the molybdenum-blue complex.

Metallic alloying elements were determined by the spectrographic procedure described in BS 1121B (1953), using, for calibration, Low-alloy-steel Spectrographic Standards issued by The Bureau of Analysed Samples. Residual metallic elements were determined by an hf-ignited dc-arc technique, with calibration based either on the BAS Mild-steel Residual Standards S811-17 or on standards specially prepared and analysed for the purpose.

Operational research studies in the forging industry

R. H. Collcutt, B.Sc.(Eng.), J. Banbury, A.M.I.E.E., and J. V. Chelsom, B.Sc.(Econ.)

SYNOPSIS

Some increase in forging output can be obtained without improvement in existing equipment, by divorcing manipulation and transporting, and by scheduling work into the furnaces, but to obtain even the present potential press or hammer performance, improved handling equipment is required, and there is great scope for saving by increasing furnace efficiency. 1740

MANAGEMENT in industry and research continually have to choose between alternative courses of action and these decisions can sometimes be made easier if a forecast evaluation of the likely outcome is available. The Operational Research Department of BISRA has been making such evaluations, both for individual forges, and as part of the Association's Forge Mechanization project. The work has been concerned with assessing the economic effects of introducing new equipment and working methods into forges, in order to assist re-equipment decisions and to indicate the value of success in various fields of research. The objectives, methods, and some of the results of this work form the subject of this paper.

The relation of these studies to other research in forging will be discussed firstly. The early stages of a series of comparative studies will then be described, followed by a report of projects for individual forges. Finally, conclusions to date will be given.

AIMS OF THE OPERATIONAL RESEARCH STUDY

The Forge Mechanization project originated because of a shortage of skilled labour and increasing difficulty in recruitment for forging. The progress of mechanization and automation in other industries and other countries prompted enquiry into the possibilities of meeting the labour shortage by the introduction of more machines to perform work previously done by hand. Some of the work of developing the equipment and controls for this purpose has been undertaken by the Mechanical Working and Plant Engineering and Energy Divisions of BISRA, and accompanying papers describe this development work. To assess the effects of these developments, and of other possible changes, studies have been undertaken in a number of forges. Results have shown that other incidental aims may also be satisfied by continuing these studies in other forges, so that their purpose has been extended as they progressed. Because changes are unlikely to be made without consideration of the associated forging costs, a measure of this effect has been incorporated in the results, and it is in this connection that the incidental aims have arisen. The objectives as they are now seen are:

(1) To assess the effect on costs and production of varying degrees of mechanization.

(2) To indicate those parts of the forging cycle where greatest cost savings can be made.

(3) From the results of (1) and (2) above, to suggest where technological research might make the greatest contribution.

(4) To measure variations in the performance of existing forges, and present the results in such a way that forge managers can compare their own performance with the rest of the industry, to see what scope for improvement exists and where the improvements can best be made.

Some of these aims are best satisfied by comparative studies of several forges; others can be met by using particular forges as illustrations. Both methods have been used and are discussed below.

COMPARATIVE STUDIES

Methods of comparison

Some forges are more mechanized than others doing similar work, and a comparison of the production times, production costs, and labour force in such forges can provide a measure of the effects of existing forms of mechanization. The main difficulties in this approach lie in finding forges with comparable patterns of work, and in isolating the effects of mechanization from the results of other factors.

The pattern of work is important because various forms of mechanization may be more suited to particular types of work. For example, consider a forge making discs and blocks. The mechanical equipment most suited for making discs may differ from that suited to blocks, and if the equipment most suited to making discs were installed in this forge, a subsequent comparison with other forges on the basis of their efficiency when making blocks only might show up this 'mechanized' forge unfavourably, while a 'discs' comparison might favour it. Since the industry is made up of a large number of firms each producing a variety of forgings it is necessary to consider ultimately the effect of mechanization on a range of work.

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Mr Collcutt is head of the Association's Operational Research Department, Mr Banbury and Mr Chelsom are members of the staff.

The interaction between stages of the forging process also affects the validity of comparisons. The stages in production are heating, transporting, and forging. If the heating or transporting processes fail to supply work to the forging unit at the required rate and in the required state, then the effects of mechanization at the forging unit may be nullified. Similarly, if forging or transporting times are such that the work cools before forging is completed, to the point where it is not hot enough to be forged, then the work must be returned to the furnace. This might interrupt the smooth flow of work through the furnace, which would offset the advantages of automation of furnacing, or even make automation impossible.

Notwithstanding difficulties of this sort, some comparative studies have been made. However, it is in the interpretation of the early results of these studies that these points become particularly important.

To obtain a first comparison it was decided to study the production of identical forgings in a number of forges, and to select for further study those where the most interesting differences were found. To obtain a wide selection of forges (for the first set of studies) a commonly made shape, size, and type of steel was chosen with the guidance of members of the industry. (The product chosen was a 4-in. square billet of Wortle tool steel.) Thus, if the differences between forges in the production of this job were located, then the generality of the differences could be checked by considering other jobs. Alternatively, if the differences found by considering only one product were themselves sufficiently interesting to forge managers, then the reasons for the differences could be sought by more detailed investigation.

In seeking to discover variations between forges, the following measures were used:

(i) time to forge a standard weight of billet
(ii) cost of forging a standard weight of billet
(iii) time to heat the ingots from which the billet was made
(iv) cost of heating a standard weight
(v) yield (i.e. the ratio of finished billet weight to starting ingot weight).

It was realized that some of these measures might be affected by influences outside the forge itself. For example, yield may be influenced by the freedom of the ingot from inclusions or surface faults, and hence by melting and casting practice. The influence of such factors could be established by the subsequent investigation of important differences found in the early studies.

The 'yield' and 'time' measures are unequivocal, but what constitutes the 'cost' of heating and forging an ingot is a moot point. The figures actually used are not the complete cost as far as the firm is concerned, but are intended only to indicate the relative effect on cost of the factors under study, namely, the equipment in the forge itself. Also, since only one type of work is included in the initial studies, it is necessary that costs shall be allocated to individual products.

The costing method used to satisfy these conditions was as follows. The 'cost per minute' of each piece of equipment was calculated, and the number of minutes that a job occupied each equipment was observed. The product of these two figures gave the cost attributable to the job.

TABLE I Equipment and men employed at the forges studied

Activity	Equipment used			
	Forge 1	Forge 2	Forge 3	Forge 4
Heating	Gas-fired pusher furnace	3-chambered furnace burning pulverized coal screw fed	2-chambered furnace burning hand-stoked and hopper-fed coal	Oil-fired pusher furnace
Transporting	Hand trolley	Manipulator	Hand trolley	Manipulator
Forging	50-cwt hammer (compressed air assisted)	4-ton hammer (steam assisted)	4-ton hammer (steam assisted)	1000-ton press (oil hydraulic)
Manipulating	Hand	Hand	Hand	Manipulator
Men employed	8	9	8	3

The cost per minute so calculated included only direct labour costs, fuel costs, maintenance costs, and an item for capital cost. Labour costs were obtained by observing the number of men employed at each equipment and multiplying by the appropriate rate of pay. Fuel and maintenance costs were obtained from works records, and adjusted where necessary because of different methods of cost allocation. The annual figure included for capital outlay was the amount which would cover the interest at 5% and repayment of a loan equal to the capital cost of the equipment in 1958, the period of the loan being twenty years for presses and hammers, and ten years for manipulators. By adding the yearly costs of labour, fuel, maintenance, and capital, a total annual cost was obtained for each equipment. This figure was then divided by the number of min/year for which the equipment was active, to give a cost per active minute. The number of active minutes was calculated as the product of the nominal number of minutes worked and the 'coefficient of utilization'. The nominal number of minutes was taken as the official length of shift multiplied by the official number of shifts per year, and the coefficient of utilization as that proportion of nominal working time for which the equipment was in active use during the period of a series of time studies.

The times for which a job occupied a piece of equipment were obtained from time studies. These studies were made in the case of forges working three shifts/day at various hours of the working day and for different teams of operators.

For the heating part of the cycle a refinement in the method was necessary. The cost per minute for the furnace was calculated in the same way, but the cost during the time for which a job occupied the furnace was not wholly applicable to that job, since other work was being charged into and withdrawn from the furnace during that period. To allow for this, a proportion of the cost of running the furnace during any one job's occupancy was allocated to that job, the proportion being the ratio of the weight of the job to the weight of the average furnace content during its time in the furnace. To do this, a record was made of the weight of the work already in the furnace when the job being studied was charged, and of all weights subsequently charged or withdrawn. Then, if the ingot being studied weighed t lb and was in the furnace for M min, and if the average furnace content during the

TABLE II Composition of the two press and hammer teams

Press (3 men)	
1 Manipulator driver	In charge of team. Drives manipulator for forging, furnacing, and disposal
1 Press driver	Operates press controls, holds measuring rod, assists in disposal, sometimes drives manipulator for furnacing
1 Furnaceman	Operates furnace doors and controls, holds marking and cutting tools, places and removes size stops on anvil, sometimes drives manipulator for forging, furnacing, and disposal
Other labour:	A shop foreman sometimes makes temperature readings. Two labourers serve the whole shop for the receipt of ingots, initial charging to furnaces, and despatch of forgings. A floor sweeper spends some of his time in press area
Note: The same team sometimes operates a 4-ton steam hammer	
Hammer (9 men)	
2 Tongmen	One of them is the first hand
2 Levermen	Only task is manipulation
1 Hammer driver	
1 Manipulator driver	Manipulator used for most furnacing, and for forging larger jobs
1 Labourer	Sweeps scale from anvil, removes tag ends, assists with hand trolley
1 Labourer	With hand trolley; also assists with levering
1 Furnaceman	Fills hoppers of automatic stokers
Other labour:	A shop foreman opens furnace doors by remote control, and controls furnaces generally

M min was *T* lb and the cost per minute of running the furnace was £*p*,

$$\text{Cost of heating ingot studied} = £p \times M \times \frac{t}{T}$$

Description of the forges studied

The equipment used in each forge for furnacing, transporting, and forging, and the number of men employed is shown in Table I.

The striking thing in this table is the small number of men used with the press–manipulator combination. That this saving did not occur in the shop using a hammer and manipulator may not be due to characteristics of the hammer or press so much as to the type of work and to management policy. The press shop was engaged on cogging only, down to 4-in. square sometimes, but more often to 6-in. square or larger, from ingots between 11-in. square and 20-in. square. For almost the whole range of work in this shop the manipulator was judged by the management to be more suitable than hand manipulation. In the hammer shop a variety of forgings was made, including shaped forgings. The management here had decided that the proportion of work of size and shape more suited to hand manipulation was sufficient to justify the retention of a hammer team of eight men.

There is a further indication that the reduction in the number of men employed is dependent on the work and policy rather than on the use of hammer or press. In the press shop a 4-ton hammer was also available as an alternative to the press and it was used for most cogging below 5-in. square. Both the press and the hammer were operated by the same team of three men.

The tasks of the members of these two press and hammer crews are described in Table II.

TABLE III Heating times and costs for Wortie tool-steel ingots about 9-in. square

Chamber or zone of furnace		Time in furnace and cost Forge 1	Forge 2	Forge 3	Forge 4
Preheating	h	16·0	12·0	13·0	6·0
	£/ingot	...	0·57	1·26	...
Soaking	h	...	5·0	...	...
	£/ingot	...	0·25	...	...
Forging	h	4·25	3·25	3·0	20·7
	£/ingot	1·0	0·55	0·54	1·05
Total time	h	20·25	20·25	16·0	26·7
Total cost	£/ingot	1·0	1·37	1·8	1·05

Note: The 'zero' cost of preheating in forges 1 and 4 is assumed because preheating consisted of placing the ingots in the path of the furnace exhaust gases

Adjustments made to obtain comparability

The finished work at each forge was of similar cross-section, but in every case there was a different starting size. Cross-sections at the head end varied between 8-in. square and $9\frac{5}{8}$-in. square, and the differences in length and taper were such that original weights varied between 475 lb and 680 lb. It was therefore necessary to adjust times and/or costs obtained at the various forges. Figures relating to German forges were available showing a directly proportional relation between ingot weight and forging time for this type of work and in the absence of other information it was decided to adjust forging times and costs in direct proportion to starting weight. The starting weight at one forge was chosen as standard and times and costs at other forges were increased or decreased according to whether their ingots were lighter or heavier than the standard ingot.

Heating costs were similarly adjusted, but the times for heating shown in subsequent sections of this report are actual times observed.

For strict comparability the question of yield must be considered. According to figures supplied by the firms visited, yield was about 75% at three of the works, but was 80% at the fourth. The effect of costing per unit of finished weight would be small, in fact it would not change the relative positions perceptibly, and has therefore been neglected so far.

If in later studies a larger difference in yields is found, it will be necessary to make an adjustment for scrap. It would be difficult, however, to make comparable cost adjustments between forges of which some have their own melting shop and others have not. In a forge which has its own melting shop, the loss on scrap is only the cost of recovering and remelting the scrap steel, plus any storing, transporting, heating, and forging costs for work done on the metal before it was scrapped. In a forge which buys its steel, however, there is the difference in cost price of steel and selling price of scrap to be considered, in addition to the processing costs.

TABLE IV Makeup of heating costs

	Forge 1		Forge 2		Forge 3		Forge 4	
No. of shifts/day	2		3		3		2	
Production, tons/year	1850		5400		1450		N.A.	
Capital cost	31 units*		83 units		12·5 units		37·5 units	
Annual costs:	Units	%	Units	%	Units	%	Units	%
Capital	2·5	12	6·4	12	1·0	6	3·0	10
Labour	3·8	18	7·5	14	5·6	35	2·5	9
Fuel	12·9	60	31·9	61	8·3	50	20·0	72
Maintenance	2·3	10	7·0	13	1·5	9	2·5	9
Total	21·5	100	52·8	100	16·4	100	28·0	100

* Cost units are based on £ sterling, but have been adjusted to preserve secrecy

TABLE V Forging times and costs for cogging Wortle tool steel to 4-in square (per 460 lb of billet)

	Forge 1	Forge 2	Forge 3	Forge 4
Forging time, min	10·7	9·3	11·0	15·2
Forging cost/min, £	0·095	0·102	0·132	0·121
Forging cost, £	0·98	0·96	1·45	1·84

Note: The cost figures are relative measures only; that is, they reflect differences in equipment, manpower, and performance, but they are not complete production costs. Some costs are omitted (e.g. rent, lighting, management) and some rates of payment have been standardized (e.g. cost of electricity, wages).

TABLE VII Comparison of heating and forging costs in four light forges

	Wortle steel cogging			Whole year (all products)		
Forge	Heating cost, £	Forging cost, £	Heating, % of total	Heating, cost*	Forging cost*	Heating, % of total
1	1·0	0·98	50	21·5	33·8	37
2	1·37	0·96	59	52·8	54·2	49
3	1·8	1·45	55	16·4	53·0	24
4	1·05	1·84	36	28·0	39·9	41

* Cost units adjusted as for Table IV

TABLE VI Utilization and its effect on cost

Forge	While forging Wortle ingots Utilization, %	Cost/ingot, £	Assuming full shift Utilization, %	Cost/ingot, £
1	58	0·98	36	1·6
2	60	0·96	35	1·6
3	50	1·45	43	1·7
4	50	1·84	39	2·3

Results of the comparative studies

The results presented relate only to heating and forging. In the forges studied the 'primary' costs of transporting, calculated by the method described, were so small as to be negligible, because of the relatively short transfer times. They may be a 'secondary' cost where transporting is carried out by all or some of the forging team. In that case forging has to stop during transporting operations, which lowers the utilization of the actual forging unit. This effect is illustrated by one of the studies described later in this paper. Results are given first for heating, then for forging and finally as the relation between the two sets of costs.

Heating times and costs

Table III shows the results relating to heating. The different heating times cannot be satisfactorily explained at present; they may be due to furnace performance, management policy for heating this steel, ignorance of maximum safe heating rates, production scheduling, or some other reason. In forge 4 some of the time and cost shown against 'forging zone' should be attributed to another part of the heating cycle, since the temperature of the cooler end of the forging zone was about 200°C lower than the corresponding parts of the other furnace systems. However, it was not possible to break these figures down further.

The makeup of heating costs for a year's work in each forge is shown in Table IV. The proportion of the total throughput formed by various types of steel varied from forge to forge, so that comparisons between forges of such things as heating cost per ton are almost meaningless. The table is included to show how total heating cost was divided between labour, fuel, maintenance, and capital.

The percentages in Table IV need care in interpretation since a reduction in, say, labour costs through, say, automatic firing, would mean an increase in the proportions of costs due to other factors, though the level of these costs would probably be unaffected. Also, although labour and maintenance costs probably increase in direct proportion with the number of shifts, fuel costs almost certainly fall as a proportion and, as calculated in this case, capital costs remain constant when the number of shifts is increased. However, the value of the figures is not so limited as to prevent the conclusion that fuel costs form the major part of heating costs.

Some measure of the scope for reducing fuel cost is given by a consideration of the thermal efficiencies of the furnaces. Whereas the amount of heat required to bring the ingots to forging temperature, and to reheat where necessary, is of the order of 10 therms/ton, the amount actually used was 54, 125, and 132 therms/ton in forges 1, 2, and 3 respectively. Part of the differences between forges may be due to more efficient forging, needing fewer reheats, as well as to more efficient furnaces. Ways of improving heating for forging are being investigated within BISRA, and are discussed in one of the associated papers. Data such as those in Table IV can be used to assess the profitability of new developments in this field, which is one aim of the studies.

Forging times and costs

The comparison of forging costs in the four forges is shown in Table V. The different costs per minute were due almost wholly to different degrees of utilization, since total costs (when allowance had been made for different numbers of shifts worked) were similar in all forges. The causes of the different degrees of utilization could not be identified from these early studies. Some likely influences are mismatching of furnace and forging capacities, the pressure of work, worker attitudes, and production scheduling.

The cost figures shown in Table V are the costs for utilizations as observed during the cogging of Wortle steel. Over longer periods, attitudes and practices (e.g. late starts, early finishes, etc.) have more effect as compared with technological factors, and the relative positions of the four forges are then changed slightly. A comparison of the two utilization figures and the effect on cost is shown in Table VI.

The lower figures for utilization over the whole shift show the scope for improvement by management alone, possibly without changes in the speed or technique of forging. Moreover, changes in forging speeds would be relatively ineffective until the utilization was increased. This is illustrated by the studies in individual forges reported later in this paper.

Comparison of heating and forging costs

The relative costs of heating and forging are shown in Table VII for cogging Wortle tool steel and for the whole year's product.

From this table it can be seen that Wortle tool steel costs proportionately more to heat than other steels worked in the four forges. This suggests that improvements in heating methods will be particularly advantageous to those forges handling a high proportion of Wortle and similar steels (hence they can afford to spend more to obtain the improvements), and that

TABLE VIII Average forging times for different teams

Forge 1 min	s	Forge 3 min	s	Forge 4 min	s
8	10	9	45	18	51
8	29	9	30	18	3

blanket allocation of heating costs will hide the true profitability of any particular type of job.

Comparison of forging methods

The way that men operate equipment may be a factor as important as the characteristics of the equipment itself. In an attempt to obtain some measure of the differences between crews' methods of working, a comparison was made within forges as far as the data collected would allow.

For three of the forges it was possible to compare forging times for identical jobs made with the same equipment by different teams. The average time for each of two crews is shown in Table VIII. The size of ingot being cogged varied from forge to forge, but within any one forge the task was identical.

In each forge the differences between forging times are small, and what there is appears to be due to native aptitude. For example, in forge 4, with the largest discrepancy, the three men making up each crew had backgrounds almost identical with their opposite number as regards age, health, experience of forging, and experience on this particular job. In all the forges the output/shift was almost the same for each work team.

The similarity of times within forges 1 and 3 was obtained in spite of differences in method. In forge 1 there was a considerable difference in the number of blows used by each crew, but the rate of striking offset this (i.e. one crew used heavier blows struck at a slower rate). In forge 3 the differences were not so marked, but one team used different methods at different periods on the same day.

TABLE IX Number of blows used to forge 460 lb of 4-in. square billet

Forge	Crew	Starting size, in. square	Number of heats	Total number of blows
1 (50-cwt hammer)	1	$8\frac{1}{2}$	3	495
	2	$8\frac{1}{2}$	2	626
3 (4-ton hammer)	1	8	2	490
	2a	8	3	476
	2b	8	2	507

The number of blows used by different teams in the two forges is shown in Table IX, and the distributions of stroke cycle time are shown in Figs.1*a* and *b*.

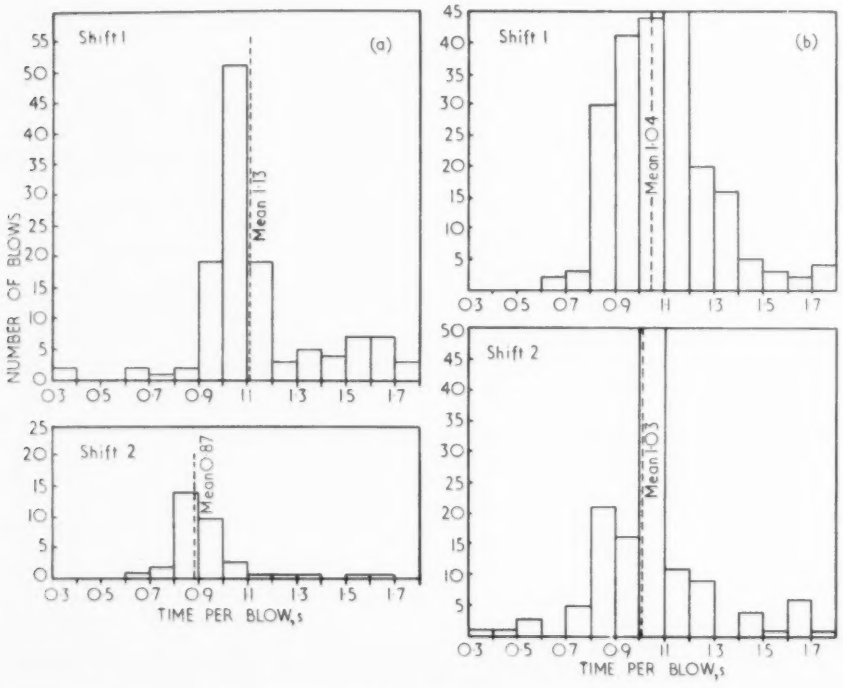
The figures in Table IX might give a pointer to the selection of a forging schedule suitable for automatic forging. An automatic forge could probably deliver heavy blows at almost the same rate as light blows, and the schedule involving least blows would then probably be the quickest and cheapest.

From the limited studies so far made, general conclusions cannot be drawn. However, the results indicate that there is ample scope for increasing forge utilization, and for reducing heating costs, particularly for steels like Wortle steel.

STUDIES OF INDIVIDUAL FORGES

A study in a medium press shop

The technical performance of a 2250-ton press was measured by the Plant Engineering and Energy Division of BISRA. The information thus collected, together with the results of time studies and cost



1 *Distributions of stroke cycle times for two different teams* (a) *forge 1, and* (b) *forge 3*

TABLE X Allocation of costs in a medium press shop

Job number	Percentage of cost attributable to: Heating	Transporting	Forging
1	67	1	32
2	74	3	23
3	62	1	37
4	70	1	29
5	89	Negligible	11
6	56	1	43
7	53	2	45
8	69	1	30
9	82	1	17
Average	70	1	29

figures, was then used in two ways. First, a calculation was made of the apportioning of cost to forging, heating, and transporting, in the same way as was described for the four light forges. The results of this are shown in Table X. The jobs studied were all different so that the average shown can only be regarded as a rough guide.

The second type of result was derived from the detailed observations made at the press during the forging of a roll for a mill. The following points were noted:

(i) the bite (i.e. the length of the forging moved into position under the tool between strokes) varied between 2 in. and 10 in., averaging 6 in., whereas the tool was large enough to allow 11-in. bites each time

(ii) ram-pressure reached only 20% of the designed capacity, so that pressing time was unnecessarily long (this was an engineering failure)

(iii) the tool was being raised higher than necessary for the movement of the workpiece.

The effect on forging time of the introduction of a mechanism for controlling the position of the ingot was estimated for three conditions. These conditions were:

(i) manual control of the press (as during the studies)

(ii) operation of the press at its maximum speed

(iii) press operation linked with the ingot position-control mechanism.

The first condition would allow the maximum bite of 11 in. for each stroke except end strokes, so reducing the number of blows needed to complete the forging from 226 to 135, and saving 8 min, or 20% of the forging time. The second condition would allow this reduced number of strokes to be made with a shorter stroke cycle time, making a total saving of about 25%. The third condition would synchronize the movement of the tool and ingot, so that the total reduction in forging time compared with the existing method would be about 30%.

The value of such a saving was assessed in terms of the heat saved. Heating the ingot through the forging range of temperatures accounted for about one-seventh of the total heating cost. A 30% saving in forging time would thus save about 30% of one-seventh of the cost of heating. This saving would probably not justify the expense of making the modification at the press.

TABLE XI Production rates at Russian press and Company's hammer

Type of production	Production rate, tons/h Hammer	Press	Press rate/ hammer rate
A	2·20	2·71	1·23
B	1·55	1·66	1·07
C	0·58	0·47	0·81
D	0·77	1·55	2·00
E	0·93	0·47	0·50
F	...	...	1·0–3·0

TABLE XII Effect of press forging rate on production time

Type of production	(i) Press forging rate/ hammer forging rate	(ii) Hammer time on this production	Time at press (ii) ÷ (i)
A	1·23	22·8	18·6
B	1·07	12·0	11·3
C	0·81	9·8	12·0
D	2·00	8·1	4·0
E	0·50	8·0	16·0
F	1·0–3·0	10·8	10·8–3·6
	Total	71·5	72·7–65·5

The possibility of increased throughput was also considered, but was found to be slight with the existing furnace system. Although a 30% saving in forging time could be made, the corresponding saving in heating time was only 30% of one-seventh of the total heating time. Therefore increased furnace capacity would be required to take advantage of the increased press availability. In fact, additional furnacing or reduced heating times would have increased throughput far more than speeding up the press, since furnace utilization was almost 100%, while press utilization was below 20% mainly through waiting for ingots to reach forging temperature. Improvements in the forging part of the cycle were therefore unlikely to pay until the heating part of the cycle had been improved.

Choosing between a hammer and a press

Another study was made on behalf of a firm to see whether a specified press shop as yet unbuilt, would be more profitable than an existing hammer shop, on the same pattern and load of work.

The capital cost of the proposed scheme was such that if the press shop were able to do the work in five shifts a week, compared with the hammer shop's fifteen, only then would the savings (in labour costs, mainly) be sufficient to make the new forge profitable. The likelihood of the press shop achieving this rate of production therefore became the centre of the study.

The organization of the new press shop was planned to give a press utilization higher than the utilization of the existing hammer, which was found to be actively forging for only 35% of the working shift. Also, it was expected that the new press would actually forge faster than the hammer. The joint effect of these two factors would have to be at least a threefold increase in production/shift in order to make the change to the press shop pay.

The press would be served by two manipulators, one of which could charge the furnaces and collect the next job while the other was working at the press. Only when the manipulators changed roles at the end of a forging operation would pressing be interrupted. The number and duration of such changeovers and the actual rate of forging had to be estimated in order to arrive at an estimate of the production/shift.

The estimate of forging rates had to be obtained in a roundabout way, since no press of the proposed type had ever been used for the range of work undertaken by the Company's hammer. However, it was possible to study a press and manipulator system similar to

TABLE XIII Effect of changed forging and handling times on makeup of production time

Activity	Time in hammer shop	Time in press shop	
		a	b
Forging	2781	2649	2649
Handling	1041	171	342
Measuring	186	186	186
Tool preparation	136	...	...

(a) assumes a 1-min changeover, and (b) a 2-min changeover

TABLE XIV Makeup of average press shift

Activity	Time per shift			
	1-min changeover		*2-min changeover*	
	min	%	min	%
Forging	316	69	300	65
Handling	21	4	39	9
Measuring	23	5	21	4
Idle	100	22	100	22
Total	460	100	460	100

that proposed. This study lasted for three days, during which time only one type of product was made but this was such that the advantages of this type of press could be fully exploited. To obtain estimated rates of production for other types of product, there being no comparable data for forges in this country, it was necessary to refer to published figures relating to Russian presses. These showed that production during the three-day study was at a rate below that for the same type of work on a 1500-ton Russian press. It was therefore assumed that the press studied would not forge faster than the 1500-ton Russian press on the other types of work included in the range undertaken in the hammer shop and that, therefore, the rates of production at the 1500-ton Russian press could be taken as an upper limit of what could be expected of the new press. These were then compared with rates of production in the existing hammer shop. It was assumed that the Russian rates related to continuous working, interrupted only for change of jobs on the anvil, and the hammer rates were calculated on the same basis. The comparison is shown in Table XI. Product F was not shown for the Russian press. A separate estimate showed that for this work press production would be 1·0–3·0 times that of the hammer, according to the type of steel.

From works' records the proportion of hammer time spent on each type of production was obtained. The effect on total production time if the same work were forged at the press was then calculated as shown in Table XII.

From Table XII it can be seen that where the hammer needed 71·5 time units the press would need between 65·5 and 72·7 time units. It was therefore estimated that the press was, on average, 1·0–1·1 times as fast as the hammer for this pattern of work. The effect of the different forging rates on press utilization was next calculated to find out how a typical shift would be made up of forging, transporting, and so on. When forged at the hammer, many jobs required more than one heat. With the faster press forging rates for some types of work, it would be possible to increase the amount of forging per heat, and hence to reduce the number of heats required. It was found that many of the jobs requiring three or four heats were those where the press was expected to be twice as fast. All such jobs could, therefore, be completed in two heats.

The work of 17 shifts was studied, and it was found that instead of needing 228 heats as at the hammer, the 138 jobs would be completed in 171 heats at the press. The handling time to and from the hammer was 1041 min, while at the press it would be the time required for 171 changes of manipulator. It was estimated that the time per changeover would be not less than 1 min nor more than 2 min, i.e. handling time would be between 171 and 342 min at the press.

The work of these 17 shifts was used to estimate the joint effect of the changes in forging and handling times. The productive time during these 17 shifts was spent forging, handling work to and from the hammer, measuring the work for cutting or shaping etc., and preparing handling tools. In the press shop handling tools would not be needed, but measuring would be unchanged. Also, as estimated above, handling time would be between 171 and 342 min, while forging would be 1·0–1·1 times as fast, say 1·05 times as fast. The effect of these changes in the use of productive time is shown in Table XIII. Thus it was estimated that in the press shop productive time would be divided between forging, handling, and measuring in the ratios 2649 : 171 : 186 or 2649 : 342 : 186 according to the time required to change manipulators.

The amount of productive time available per shift was estimated by considering the disposition of time during hammer shifts, and by obtaining the management's opinion of what would be changed. The result of this was an estimated non-productive time of 100 min/shift, through rest periods, bad time-keeping etc., and productive time of 360 min.

The 360 min were divided in the ratios given above, to produce the following shift, which is shown in Table XIV for the two limiting manipulator changeover times.

The press utilization was therefore estimated as likely to be between 65% and 69%, compared with hammer utilization of 35%. Also the press forging rate would be 1·0–1·1 times the hammer rate. Production/shift in the press shop would therefore be between

$$1{\cdot}0 \times \frac{65}{35} \text{ and } 1{\cdot}1 \times \frac{69}{35}$$

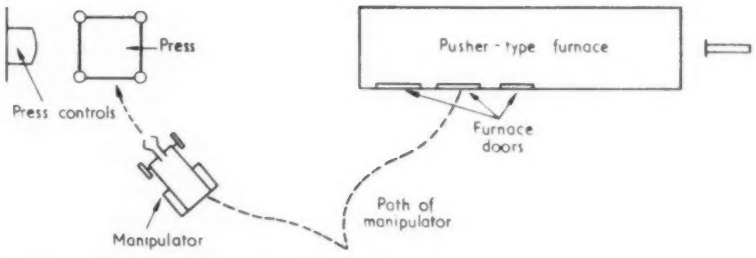
i.e. between 1·8 and 2·1 times the hammer shop production. This is well below the rate of 3·0 required to make the press more profitable than the hammer.

Possible changes that would make the press shop more profitable were then considered. These were (*a*) a change in the pattern of work, and (*b*) an increase in the press forging rate.

From Table XI it can be seen that for some types of work the press is much faster than the hammer, while for other types it is slower. If the hammer work of types C and E were replaced by work in the other group for the change to press working, then press production per shift would be between 2·6 and 2·8 times the hammer production. The press shop would then roughly break even on one-shift working.

TABLE XV Press stroke cycle times with and without manipulator

Bite size, in.	2	2	4
Penetration, in.	½	1	1
Stroke cycle time, press only, s	1·04	1·33	1·33
Stroke cycle time, press + manipulator, s	1·40	1·46	1·60



2 *Diagrammatic layout of forge*

The similarity of the press and manipulators specified for the new shop and the press and manipulator that were time-studied consisted of a similarity of theoretical stroke cycle times as well as similarity in design. The cycle times were calculated from the manufacturers' specification of press and manipulator performance. In making these calculations it was found that, as specified, the manipulator would prevent the press from operating at its designed speed. The extent of this delay is illustrated by Table XV.

These differences were similar for both presses, and are based on specifications only. There were in practice additional delays, caused by human reaction times, and because the manipulator was unable to accelerate at its designed rate due to slipping between the drive wheels and the forge floor.

The sum of these effects was that the observed stroke cycle times were double the designed times. If this were corrected the press shop could be made to pay. (This effect occurs also in the next example.)

It was also shown that if the press shop worked two shifts, taking over part of the work of a second hammer shop (there were several in the works concerned), then it could be made profitable. Similarly, if the press were operated for three shifts a day, taking over work from a number of other hammer shops, then again it would pay. At the same time there would be a drop in the number of men required, three press teams replacing up to nine hammer teams.

The effects of changes in a forge's handling equipment

The studies of the cogging of a high-speed tool steel at a rapid-stroking 1000-ton press were also used to evaluate possible changes in the handling equipment of the forge. During observations a mobile manipulator was used at the press, and for transporting work between the furnaces and the press, and for removing finished forgings across the shop. The layout was as shown in Fig.2.

It was noted that the stroke cycle times actually obtained were about double the time which the press could theoretically have achieved for the penetration being used. The press was being delayed in its downstroke to allow the manipulator time to position the job, and the manipulator was unable to reach its designed acceleration because the driving wheels were slipping on the forge floor.

The time spent on various activities during a shift was as follows:

Official breaks	45	min
Press working (with manipulator)	160	,,
Manipulator transporting, furnacing (press idle)	191	,,
Waiting for heats	84	,,
Total	480	,,

The changes that were considered were:

(i) improved manipulator performance at the press, so that the press could reach its designed speeds, but transporting and charging times unchanged

(ii) manipulator performance improved as in (i) but with corresponding improvement (i.e. doubling) of transporting and charging rates

(iii) manipulator performance unchanged, but a second identical machine introduced for transporting and charging

(iv) manipulator performance unchanged at the press, but a charging machine introduced, fast enough to eliminate transport delays, (i.e. about 20% faster than present machine)

(v) improved manipulator allowing press to reach designed speeds, and charging and transporting equipment fast enough not to keep the press waiting (i.e. furnacing and transporting in about half the present time).

Some of the postulated changes may appear unreasonably optimistic, but with comparatively minor alterations in working methods they become feasible, and this study was intended to find out how worthwhile they would be in this forge. For example, work could be transferred from the furnace to the anvil by, say, a powered roller table, or rail-bound table with push-pull jaws for extracting and depositing the ingot, instead of a mobile machine taking the devious route shown in Fig.2. Similarly, although it would be impossible to double the longitudinal travel speed of the rear-wheel drive manipulator now used at the press, a machine with rack and pinion or four-wheel drive could probably obtain these speeds. In any event, the changes were assumed in order to see whether, in terms of reduced cost, it would be worthwhile developing the necessary equipment.

The effects of the various changes on the volume of production and on production costs were calculated assuming that the same number of shifts/year was worked. The changes in production were obtained by considering (*a*) the change in active press time per shift, and (*b*) the change in press forging speeds.

A figure for the gross annual saving was calculated, which showed the difference between the cost of producing the new tonnage in the modified shop, without allowing for the costs of the changes made, and the cost of producing that tonnage in forges like the existing forge. This gross annual saving then represents the maximum amount that could be spent annually to implement the changes. In all cases it was assumed that heating costs per forging were constant, though with increased throughput these could probably be reduced.

Although the number of shifts per year was assumed

TABLE XVI Savings available to finance new schemes

Scheme (All working same number of shifts as at present)	Increase in production, % of present output	Annual savings, £/year
1 Faster manipulator to match press speeds. Same furnacing speeds	59	5 850
2 Manipulator faster at press and for furnacing. (One machine only)	118	11 350
3 Manipulator unchanged at press. Similar manipulator introduced for furnacing	59	8 300
4 Manipulator unchanged at press. Charging machine fast enough to avoid delays	79	10 000
5 Manipulator to match press. Charging machine fast enough to avoid delays	248	28 600

unchanged, the time for which the press was active would increase for each scheme. The running costs of the press and, when retained, the manipulator, were calculated for the new scheme under the following assumptions:

(i) fuel and maintenance costs change in proportion to the time for which the equipment is active

(ii) annual capital and labour costs are unchanged.

It may in fact be necessary to increase wages or the number of men employed, but this would be one of the costs of implementing the scheme, to be deducted from gross annual savings.

The results of these calculations are shown in Table XVI. An assumption inherent in the above method of costing the new schemes is that a market is available for the increased output. Where the only saving to be made is by reducing the working time required to produce the same amount of forgings, the only schemes that might pay are those where a complete shift per day is saved. (This might tend to increase heating costs per forging, but a complete shift's labour would be saved.) Under these circumstances the estimated savings would be as shown in Table XVII.

Of the five schemes considered only scheme 3 does not involve equipment with improved performance. The only change postulated in this scheme was the introduction of a second manipulator, and this produced an increase in output of almost 60%, with a gross saving of £8300/year compared with making the increased output in a forge like the one studied. When the costs of running a manipulator as a charging machine for two shifts have been deducted, the net saving would be about £5000/year, and the capital cost involved would be about £15000.

For those schemes where faster forging is assumed, there is an associated saving in handling time because the required number of reheats is reduced. This effect was more pronounced in the forge studied than in general, because the work, cogging high-speed tool steel, involved more reheating than is usual. Where handling does not occupy so large a proportion of the time (in this forge it accounted for 191 min in a 480-min shift) the scope for increasing output by reducing the number of handling operations, or by introducing separate or faster handling equipment, is obviously not so great.

However, the figures in Table XVI do show the importance of improved handling equipment, for in none of the schemes was any improvement in the press itself included.

TABLE XVII Savings available to finance new schemes, with present production

Scheme	Production time required, % of present 2 shifts	Annual saving, £/year
1	63	nil
2	46	1 850
3	63	nil
4	56	2 800 minus overtime costs for 12% of 1 shift
5	29	3 000

CONCLUSIONS

From the comparative studies and the studies in particular forges a number of general points have emerged. The central feature is the low utilization of the actual forging equipment, which is partly caused by inefficient or insufficient furnacing, partly by inadequate handling equipment, and partly by other factors, including inadequate production programming.

It appears that the proportion of cost within the forge attributable to heating varies, according to the size and type of work, between about 30% and 80% of the total forging costs. In all forges studied the major part of heating costs has been due to fuel, which constitutes up to 70%. This high fuel cost is associated with low thermal efficiencies of the furnaces. (Up to about fourteen times the required amount of heat was used to heat ingots for forging in the forges studied. A subsequent wider study by another department of BISRA noted instances where up to forty times the theoretically required amount of heat was used.) In addition to these direct costs, delays waiting for heats lower the press or hammer utilization, so adding to the cost of the actual forging operation.

Where it is desirable to obtain high forge utilization it is necessary to divorce the manipulating and transporting functions. This division should extend to equipment as well as to personnel, since the properties required in a manipulator at the press or hammer are different from those required of a charging and transporting machine.

At the anvil rapid longitudinal, rotational, and possibly, lateral movements are required over short, exact distances. The part of the ingot between the tools must be free for working. This means that the manipulator at the press must have high rates of acceleration, be able to grip the ingot at the ends, and should lend itself to automatic position control. To achieve this, the gripping and moving parts of the manipulator must be as light as possible; there is no room for dead weight in the form of motors or counterbalances. Drive through road wheels is dependent on friction which is limited, so that a more positive drive, through rack and pinion, or hydraulic rams, or springs, is likely to be required. (If drive through road wheels is retained, a change in weight distribution or to four-wheel drive might be made to obtain higher accelerations.) Motors could be floor mounted, and the weight of the job taken by roller tables. By changes such as these, manipulators may be made to match the high stroking rates already being obtained by presses and hammers. But when such speeds are reached manual

control may not be feasible. Also, a man could not be expected to spend his day subjected to continual accelerations and braking of this order. It would therefore become necessary to consider remote controls and programmed forging.

If transporting is carried out by a separate machine during forging, then high travelling speeds are not essential, and a machine similar to present mobile manipulators may sometimes be suitable. However, since the machine would not have to manipulate the job at the anvil, it would no longer be necessary to carry the job around by one end. The work could be carried underslung or on a table, making counterweights unnecessary, and spreading the load evenly, so that drive through the road wheels would be more effective.

With higher utilizations and forging rates, the scheduling of work into the furnaces so as to avoid delays waiting for heats will become more important. Already time is often lost through waiting for a job to reach forging temperature, and such delays will become proportionately longer, and probably more frequent, as other delays are removed and throughput increased. In order that efficient schedules can be drawn up, more knowledge of maximum safe heating rates is required. To apply this knowledge more information about temperature states inside the furnace will be necessary, together with tighter control over changes in those temperatures. However, even with variations in heating and forging times as at present, scheduling can increase production without any change in furnace or forge performance.

Spread and elongation in flat tool forging

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SYNOPSIS

Predictions of the elongation and sideways spreading which occur when forging square bars with flat tools, can be made from information given in this paper. Data from carefully controlled forging experiments has revealed an empirical relation governing the change of shape in each pass, which is expressed in a simple graphical form. In addition, the results indicate that each forging stroke contributes most to the elongation of a forging when wide tools and heavy reductions are used.

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INTRODUCTION

THE ADOPTION of definite rules, in place of empirical methods for controlling changes of shape in rolling and forging was first suggested by Tresca in 1867.[1] Present-day procedures in open die forging are still based on the individual forgemaster's experience and observation, mainly because each forging stroke produces both elongation and sideways spreading, the amounts of which cannot be predicted in advance.

In view of current interest in improved, and possibly automatic, techniques of forging an investigation was undertaken to determine the rules which govern spread and elongation in flat tool forging, as a first step in establishing better forging techniques. This paper describes experimental work on square bars from which results were obtained which can be used in industrial forging. The experiments are compared with tests taken by Tarnowski on rectangular blocks.[2]

EXPERIMENTAL WORK

Scope of experiments

The primary object of the work was to provide data for predicting the changes of shape produced during any single pass when forging square bars with flat tools. The changes of length and width of a series of test bars were determined after a single forging pass consisting of strokes with identical depths of squeeze and longitudinal movement of the bar between strokes. The results obtained from the tests may be used for predictions on larger forgings because previous investigations[1-3] have shown that the principle of geometric similarity is applicable to forging processes.

The effect of the following factors on the change of shape of the test bars was investigated:

(i) temperature of the test bar
(ii) reduction of height
(iii) longitudinal movement of the bar between strokes
(iv) shape of cross-section
(v) curvature of the side faces produced by previous forging.

The effect of forging temperature on dimensional changes was examined by carrying out tests on bars at different temperatures within the range 1000–1250°C.

The range of reductions in height normally used in forging was also examined to see whether the proportion of spreading to elongation varied with different reductions. The reduction was expressed as the ratio:

$$\frac{\text{height of bar after forging}}{\text{height before forging}} = \frac{h_1}{h_0}$$

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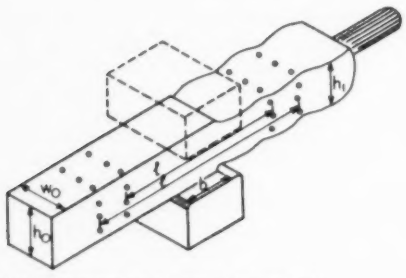
The authors are on the staff of the Mechanical Working Division at the Association's Sheffield Laboratories.



1 *Method of measuring change of dimensions*

During normal bar forging the bar is moved longitudinally between strokes. The length of stock newly presented to the tools on each stroke will be called the bite and when expressed as a proportion of the width of the bar will be termed the bite ratio:

$$\text{bite ratio} = \frac{\text{bite}}{\text{bar width}} = \frac{b}{w_0}$$

A range of values of this ratio was investigated; it was known qualitatively that small bites gave less sideways spreading than large bites.

Bars of different cross-sectional shape were tested because when forging a square bar the section alternately changes from one oblong shape to another, although the departure from square is not large. The shape of cross-section of each test bar was expressed as the ratio:

$$\frac{\text{initial height of bar}}{\text{initial width}} = \frac{h_0}{w_0}$$

After one forging pass on a square bar the side faces take on an irregular shape, commonly termed barrelling, which is due to frictional constraint at the tool faces and to the influence of the adjacent undeformed portion of the bar. To compare the effect of forging on previously barrelled surfaces with that on flat faces, several of the bars on which a first test had been completed were later reforged on the barrelled faces employing similar reductions and bite ratios as before.

The tests were made on steel of low-carbon quality (0·2%C), but the results obtained should be applicable to other steels judging by concurrent work in hot rolling, which has shown that spread characteristics are virtually unaffected by variation in steel composition.

Experimental procedure

The laboratory equipment, which consisted of a 200-ton press and manipulator, dictated the sizes of the test bars and the experiments were made on bars of 3-in. to 8-in. section, in lengths up to 4 ft.

The temperature of each bar during heating and forging was recorded from three Pt/Pt–Rh thermocouples positioned towards the mid-length and inserted diametrically to the axis, the mid-radius, and to within $\frac{1}{8}$ in. of the outer surface. Each bar was rapidly heated by charging cold into a furnace at 1300°C to 1400°C and withdrawn immediately the centre reached the required temperature. This minimized oxide scaling but had little effect on the temperature gradient in each bar during testing, because although the surface was hotter than the inside during heating, it was cooler by the time the bar was positioned ready for forging. The temperature given for each test is the average of the surface, mid-radius, and central temperatures half-way through each test, quoted to the nearest 10°C. A typical time for transporting and positioning each bar for forging was $1\frac{1}{2}$ min; each single pass test took about 1 min.

TABLE I Tests on bars with flat surfaces

$\frac{b}{w_0}$	$\frac{h_0}{w_0}$	$\frac{h_1}{h_0}$	Mean temperature, °C	Temperature gradient, °C surface to centre	Spread coefficient, s
2·03	1·00	0·905	1180	70	0·64
1·98	1·00	0·903	1180	59	0·66
1·81	1·00	0·847	1130	47	0·62
1·88	1·00	0·803	1230	86	0·65
1·86	1·10	0·780	1130	47	0·67
1·92	1·51	0·899	1190	67	0·58
1·86	1·52	0·799	1200	71	0·60
1·48	1·00	0·904	1220	84	0·55
1·44	1·00	0·898	1040	22	0·56
1·37	0·99	0·871	1140	95	0·54
1·34	1·00	0·834	1020	63	0·55
1·43	1·00	0·802	1220	60	0·58
1·30	0·99	0·728	1170	59	0·55
1·44	1·25	0·900	1180	80	0·50
1·00	1·01	0·906	1090	48	0·42
0·93	1·00	0·904	1010	54	0·41
0·98	1·00	0·900	1190	44	0·41
0·92	0·99	0·886	1220	84	0·41
0·93	1·00	0·797	1230	86	0·41
0·87	1·01	0·773	1190	82	0·42
0·99	1·25	0·908	1180	74	0·41
0·92	1·25	0·797	1180	68	0·42
0·55	1·01	0·933	...	...	0·34
0·51	1·00	0·903	...	...	0·32
0·55	1·00	0·903	1030	86	0·28
0·50	1·00	0·886	...	...	0·32
0·51	1·00	0·841	...	...	0·32
0·53	1·00	0·803	1030	...	0·29
0·52	1·00	0·799	1070	60	0·32
0·56	1·24	0·901	1030	116	0·31
0·52	1·24	0·802	1070	101	0·32
0·31	1·00	0·902	1010	86	0·23
0·31	1·24	0·900	1040	105	0·26

The reduction of height in each test was controlled in some cases by use of the automatic control device of the press, and in others by means of spacer blocks between the press tools. The speed of deforming each bar was roughly regulated to be proportional to the bar height and varied between $\frac{3}{4}$ in./s, and $1\frac{1}{2}$ in./s. To obtain the bite for each stroke, the manipulator positions were measured.

The method of measuring the effect of each single pass test is indicated in Fig.1. Before forging the mean height and width of each bar was obtained from an average of about 40 micrometer measurements each. The values were adjusted during calculation to allow for the slight oxide scaling occurring during heating. For length measurements, small holes were drilled on each face of the bar some distance from each end to avoid end effects, and the length between the 24 corresponding pairs of holes measured. When the test bars had cooled after forging the height and gauge lengths were remeasured.

The change of height and length of the bars was expressed in terms of the ratios between the original and final sizes. A similar ratio defining the average change of width could then be calculated because the volume of the forging remains unchanged, the three ratios being related as follows:

$$\frac{\text{volume before forging}}{\text{volume after forging}} = \frac{h_1}{h_0} \times \frac{w_1}{w_0} \times \frac{\ell_1}{\ell_0} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The final width (w_1) obtained from the calculation is equal to the dimension which would be obtained if a true average over the barrelled faces had been measured.

Analysis of results

From equation (1) above, the following formulae can be derived (*see* Appendix I).

$$\frac{w_1}{w_0} = \left(\frac{h_0}{h_1}\right)^s \text{.....(2), and } \frac{\ell_1}{\ell_0} = \left(\frac{h_0}{h_1}\right)^{1-s} \text{.....(3)}$$

These enable the change of width and length of any size of bar to be determined knowing the change of height and the numerical value of the exponent s. The change of height is expressed in the form h_0/h_1 as being more convenient than the inverse term h_1/h_0.

The exponent s will be termed the coefficient of spread, formally defined in Appendix I as the ratio between the lateral and vertical natural strains. It is a measure of the proportion of the deformed material moving into sideways spread. If s were unity then the whole of the deformation would exhibit itself as spread, whereas if s were zero there would be no side-spread, only elongation.

The object of the analysis of the test results was to establish numerical values of the spread coefficient (s) which could be employed in practical forging operations, by finding the effect on s of each factor varied in the experiments.

The value of s was calculated for each experiment and the results are given in Table I for flat bars, and Table II for bars forged on barrelled surfaces, together with the associated values of bite ratio, height/width ratio, reduction, mean temperature, and temperature difference between the surface and centre of the bar. Inspection of the tables, which are grouped according to bite ratio, shows the bite ratio to be the main factor affecting the value of s, and this has been used as the abscissa of Fig.2, where the values are plotted.

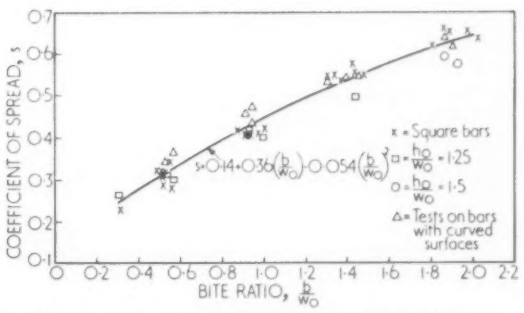
It was not clear whether the other factors influenced the spread coefficient, or whether the variations were due to experimental error, so the results were analysed by statistical methods. These showed the following:

(i) when all the 43 test results were taken together, both the bite ratio and the height reduction affected the value of the coefficient, according to the formula

$$s = 0{\cdot}29 - 0{\cdot}16\left(\frac{h_1}{h_0}\right) + 0{\cdot}343\left(\frac{b}{w_0}\right) - 0{\cdot}048\left(\frac{b}{w_0}\right)^2$$

TABLE II Tests on bars with curved surfaces

$\frac{b}{w_0}$	$\frac{h_0}{w_0}$	$\frac{h_1}{h_0}$	Mean temperature, °C	Temperature gradient, °C surface to centre	Spread coefficient, s
1·87	1·29	0·847	1150	95	0·64
1·90	1·48	0·772	1190	36	0·62
1·46	1·17	0·898	1140	57	0·55
1·39	1·24	0·871	1160	47	0·54
1·31	1·61	0·718	1210	34	0·54
0·94	1·15	0·898	1200	70	0·43
0·91	1·19	0·878	1200	98	0·46
0·94	1·53	0·720	1160	85	0·48
0·54	1·14	0·903	1050	68	0·35
0·57	1·24	0·827	1200	88	0·37


COEFFICIENT OF SPREAD, s
BITE RATIO, b/wo
x = Square bars
s = 0·14 + 0·36(b/wo) − 0·054(b/wo)²
□ = ho/wo = 1·25
○ = ho/wo = 1·5
Δ = Tests on bars with curved surfaces

2 *Relation between coefficient of spread and bite ratio*

(ii) the effect of the height reduction, although statistically significant, was small and on omitting it from the analysis, a suitable relation was found to be

$$s = 0{\cdot}14 + 0{\cdot}36\left(\frac{b}{w_0}\right) - 0{\cdot}054\left(\frac{b}{w_0}\right)^2 \text{.....(4)}$$

(iii) if the tests made on square bars only were considered (i.e. 25 results) and bars with other cross-sectional shapes or barrelled surfaces excluded, both bite ratio and reduction were again found to be significant factors

(iv) when the 10 results on bars with curved surfaces were considered by themselves, the only factor which significantly affected the spread coefficient was the bite ratio

(v) the temperature of forging, the temperature gradient in the bars, and the shape of cross-section had no significant effect on the value of s

(vi) the bite ratio and the reduction accounted for most of the variance in the experimental values of s. The small amount of residual variance indicated that there were no unknown factors having an appreciable systematic influence on the spread coefficient.

DISCUSSION

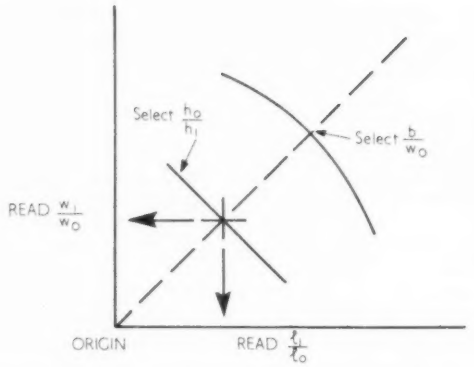
The analysis indicates that the coefficient of spread derived for bar forging depends mainly on the shape of the tool contact area, as defined by the bite ratio. Equation (4) should predict the coefficient with sufficient accuracy for practical purposes, and it is superimposed on the tests results in Fig.2. It should be satisfactory for predictions on bars with previously barrelled surfaces although it may under-estimate slightly the spreading for such bars when forging with bite ratios of 0·5 or less. The exclusion of the effect due to reduction of height does not cause measurable inaccuracy for practical usage.

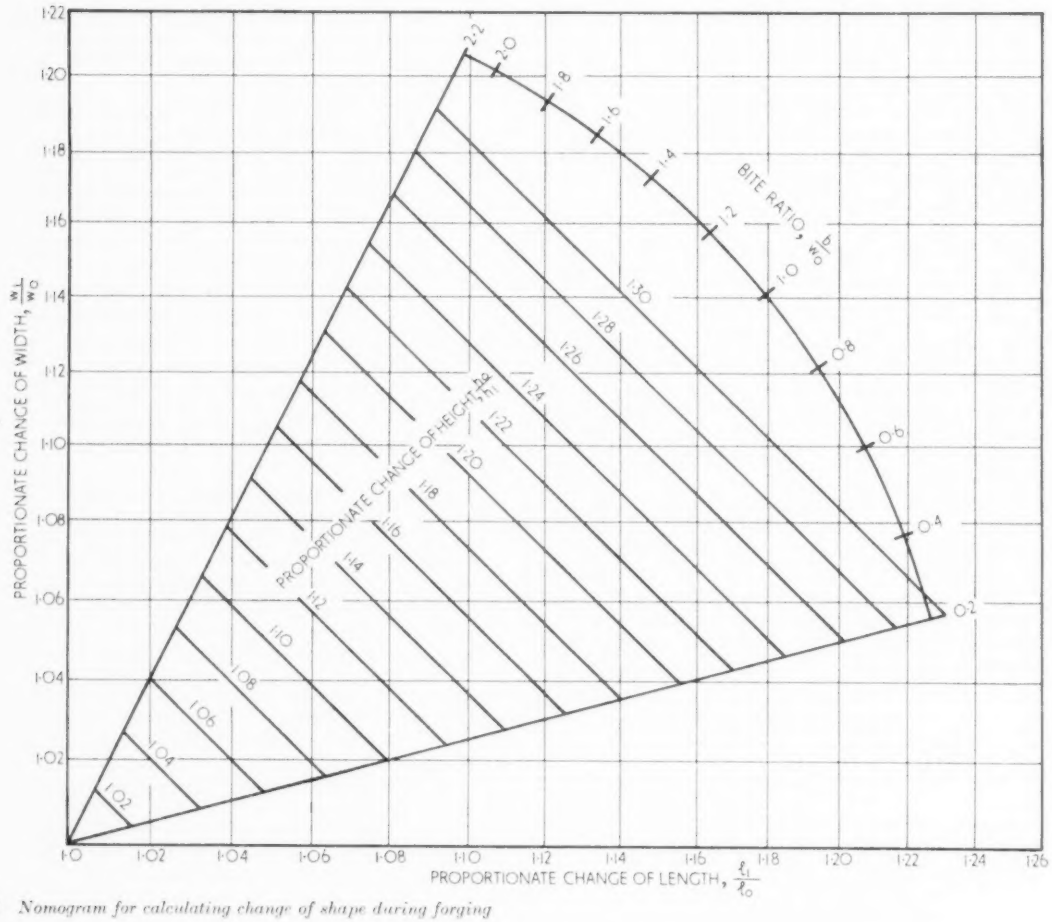
The analysis showed no effects attributable to forging temperatures or cross-sectional shape and indicated that there were no other factors to consider. In particular, the lack of any effect due to thermal gradients suggests that any effect in large forgings with steeper gradients should be slight.

The tests have revealed that less spreading occurs during the forging of a bar than during the compression of comparable rectangular blocks between completely overlapping tools. From the results of

Method of use

1. Place straight edge between origin of graph and selected value of b/w_0 inscribed round quadrant
2. Locate point of intersection of straight edge with selected value of h_0/h_1
3. Project the point of intersection to the vertical and horizontal axes and read off w_1/w_0 and l_1/l_0





3 *Nomogram for calculating change of shape during forging*

published experiments[2] on such blocks, which are summarized in Appendix II, it appears that the spread coefficient for blocks can be predicted by the simple equation $s = b/(b + w_0)$. The reduced spreading in bars is presumably due to the constraining effect of the bar material extending outside the tools. At the 1 : 1 bite ratio in particular this is the only explanation, because for blocks the lateral and longitudinal extensions are equal and the spread coefficient must be equal 0·5. (In bar forging the value of s is 0·44).

Industrial application

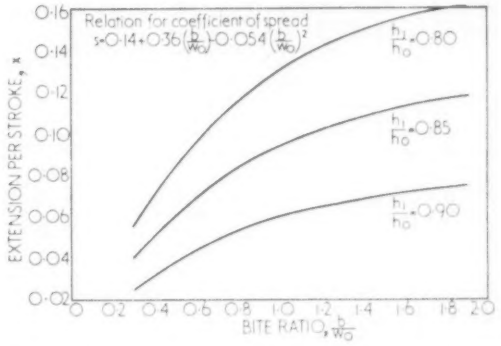
The effect of forging a square or rectangular bar between flat tools can be predicted from the results in this paper. Equations (2) and (3) may be used, together with the appropriate value of s from Fig.2. Alternatively, the nomogram of Fig.3 may be employed to cut down calculation. Predictions may be made on any size of forging, the absolute dimensions of the stock before and after forging being converted into ratios and the tool bite being expressed as the ratio

between the absolute size of the bite and the width of the bar.

In addition, the increase in length produced by individual forging strokes can be calculated and compared for different height reductions and bite ratios. The relation in Appendix III defines the increase in length attributable to each stroke, expressed as a ratio of the width of the bar. Sample calculations, illustrated in Fig.4, show that the extension per stroke increases with both the reduction and the bite.

To achieve a large elongation on each stroke, therefore, both the height reduction and the bite should be large. Permissible height reduction is largely a matter of the forgemaster's experience and depends on features not considered in this report. Means of increasing it might well be sought, however, because increased reductions do not require any great increase in forging load as is shown by stress/strain curves available for steels at high temperatures.[4, 5]

For a given height reduction, the extension increases relatively quickly as the bite ratio increases to just above 1; thereafter the extension continues to increase, but at a progressively reduced rate. Observations in various forges indicate that bite ratios used at present decrease as the size of forging unit increases. On smaller hammers ratios of 1–2 are common, but on presses bite ratios of 0·2 and 0·3 are typical, and if these were to be increased larger presses would be required. The most economical bite ratio to use in a forging operation is considered in an accompanying paper.[6] which deals with complete forging schedules. Other factors to be considered in selecting a suitable bite ratio concern the consolidation of central looseness in forging ingots. Studies by Cook[7] have shown that the centre of a forging undergoes higher compressive strains when large bites are used and studies of upset forging[8] have indicated that cavities close more readily when the tool contact area is large relative to the height of the forging.



4 *Relation between extension per stroke, bite ratio, and reduction*

CONCLUSIONS

The change in shape due to any pass when forging square sections with flat tools can be predicted from the information in this report; most simply by using the nomogram in Fig.3. Such predictions are essential for deriving complete forging schedules dealt with elsewhere.[6]

The spread coefficient, on which calculations are based, has been measured experimentally to provide general values of practical use. The values depend principally on the length of the tool contact during each stroke expressed herein as the bite.

Other calculations based on the test results show that an individual forging stroke contributes more to the extension of a bar as both the reduction and the bite increase. Larger reductions appear to be desirable, but the best bite size to use in any forging operation depends upon other considerations.

ACKNOWLEDGMENTS

The authors wish to record their appreciation of the help given by their colleagues, especially Mr N. Bullas for his careful experimental work, and Mr P. Armitage for the statistical analyses.

They are also indebted to Mr W. C. F. Hessenberg, Deputy Director of BISRA, and Mr A. Shutt for developing the nomogram.

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APPENDIX I

PREDICTION OF CHANGE OF SHAPE DURING FORGING

A general method of predicting the change of shape during each forging pass can be derived by manipulating the constant-volume law in the following way.

In terms of the geometric ratios measured in the experiments, constant volume gives:

$$\frac{h_1}{h_0} \times \frac{w_1}{w_0} \times \frac{\ell_1}{\ell_0} = 1$$

in terms of logarithmic strains this becomes:

$$\log \frac{h_1}{h_0} + \log \frac{w_1}{w_0} + \log \frac{\ell_1}{\ell_0} = 0$$

$$\therefore \log \frac{w_1}{w_0} + \log \frac{\ell_1}{\ell_0} = -\log \frac{h_1}{h_0}$$

and

$$\frac{\log \frac{w_1}{w_0}}{-\log \frac{h_1}{h_0}} + \frac{\log \frac{\ell_1}{\ell_0}}{-\log \frac{h_1}{h_0}} = 1$$

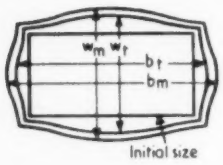
if

$$\frac{\log \frac{w_1}{w_0}}{-\log \frac{h_1}{h_0}} \text{ is termed } s, \text{ then } \frac{\log \frac{\ell_1}{\ell_0}}{-\log \frac{h_1}{h_0}} = 1 - s$$

s will be termed the coefficient of spread.

TABLE III Data extracted from Tarnowski's experiments

$\frac{b_0}{w_0}$	$\frac{h_0}{w_0}$	$\frac{h_1}{h_0}$	Calculations from experimental results $\frac{\log(w_1/w_0)}{\log(b_1/b_0)} \cdot s$		Values predicted by Golowin's theoretical equations $\frac{\log(w_1/w_0)}{\log(b_1/b_0)} \cdot s$	
Steel, hammer-forged at 1000°C						
3·43	1·0	0·54	3·54	0·78	4·58	0·82
2·36	1·0	0·46	2·33	0·70	2·84	0·74
1·96	2·0	0·39	1·88	0·65	2·21	0·69
1·52	1·0	0·43	1·54	0·61	1·69	0·63
1·47	0·5	0·55	1·65	0·62	1·70	0·63
As above, but b and w transposed						
0·29	0·29	0·54	0·28	0·22	0·22	0·18
0·42	0·42	0·46	0·43	0·30	0·35	0·26
0·51	1·02	0·39	0·53	0·35	0·45	0·31
0·66	0·66	0·43	0·65	0·39	0·59	0·37
0·68	0·34	0·55	0·61	0·38	0·59	0·37
Duralumin, hammer-forged at 500°C						
3·38	1·0	0·62	3·88	0·80	4·73	0·83
3·02	1·0	0·43	3·47	0·76	3·65	0·79
2·69	1·0	0·47	3·02	0·75	3·32	0·77
2·02	1·0	0·42	2·23	0·69	2·33	0·70
As above, b and w transposed						
0·30	0·30	0·62	0·26	0·21	0·21	0·17
0·33	0·33	0·43	0·29	0·24	0·27	0·22
0·37	0·37	0·47	0·33	0·25	0·30	0·23
0·50	0·50	0·42	0·45	0·31	0·43	0·30



Average final width, $w_1 = \frac{w_f + w_m}{2}$

Average final length, $b_1 = \frac{b_f + b_m}{2}$

The final equations can be rewritten in the forms:

$$\frac{w_1}{w_0} = \left(\frac{h_0}{h_1}\right)^s \text{ and } \frac{\ell_1}{\ell_0} = \left(\frac{h_0}{h_1}\right)^{1-s}$$

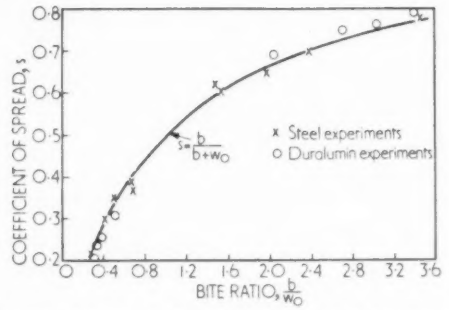
APPENDIX II

SUMMARY OF DATA EXTRACTED FROM EXPERIMENTS BY TARNOWSKI

Experimental work has been previously reported on the compression of rectangular blocks deformed between tools completely covering the blocks. Of this the only experiments providing sufficient information from which calculations could be made are due to Tarnowski.[2]

He proposes, from theoretical considerations, the generally accepted view that in the absence of surface friction a compressed block would deform uniformly and preserve the same length/width ratio throughout deformation. This implies that the strains in the width and length directions are equal for all shapes of block and the coefficient of spread, s, would have a constant value of 0·5.

Under practical conditions frictional constraint occurs, and experiments were done by Tarnowski to check theoretical predictions of change of width and length of rectangular blocks put forward by Golowin for frictional conditions. Golowin's equations are given below in the forms which are applicable when b (the length of the block) is greater than w (the width).



5 *Relation between coefficient of spread and bite ratio for rectangular blocks (Tarnowski)*

Change of width: $\frac{w_1}{w_0} = \frac{h_0}{h_1} \cdot \frac{1}{\sqrt{1 + \frac{w_0}{b_0}\left[\frac{h_0}{h_1} - 1\right]}}$

Change of length: $\frac{b_1}{b_0} = \sqrt{1 + \frac{w_0}{b_0}\left[\frac{h_0}{h_1} - 1\right]}$

The materials tested by Tarnowski included steel, hammer-forged at 1000°C, and duralumin, similarly forged at 500°C. The experimental information and the values predicted by Golowin's theoretical equations have been transposed to logarithmic strains, and the data are given in Table III. It should be noted that each test provides two b/w values, depending on the directions in which w and b are measured. The method used by Tarnowski to obtain the average width and length dimensions after compressing is shown in Table III.

The data suggests that the simple relation $\frac{\log(w_1/w_0)}{\log(b_1/b_0)} = \frac{b}{w}$ defines the deformation better than the more complex equations predicted by Golowin.

Using the constant-volume law the relation suggested above indicates that the value of s for rectangular blocks is defined by the relation $s = b/(b + w_0)$. Figure 5 shows that the experimental values of s for both steel and duralumin closely follow this relation.

The theoretical predictions by Golowin over-estimate the value of s when b/w_0 is greater than 1 and give an under-estimate for b/w_0 less than 1.

APPENDIX III

CALCULATION OF EXTENSION PRODUCED PER STROKE

The extension produced by each stroke in a forging operation can be calculated as follows:

The extension per pass $= \ell_1 - \ell_0$

The number of strokes per pass $= \frac{\ell_0}{b}$

$\therefore$ the extension per stroke $= \frac{b(\ell_1 - \ell_0)}{\ell_0} = b\left[\frac{\ell_1}{\ell_0} - 1\right]$

Dividing through by w_0 gives the extension as a proportion of the bar width. This function will be termed X.

$$X = \frac{b}{w_0}\left[\frac{\ell_1}{\ell_0} - 1\right]$$

from Appendix I $\left(\frac{h_0}{h_1}\right)^{1-s}$ can be substituted for $\frac{\ell_1}{\ell_0}$

$$\therefore X = \frac{b}{w_0}\left[\left(\frac{h_0}{h_1}\right)^{1-s} - 1\right]$$

Theoretical analysis of bloom and billet forging

J. G. Wistreich, D.Sc.(Eng.), and A. Shutt, B.Sc.

SYNOPSIS

A theory has been developed for the cogging of square blooms and billets by means of flat tools, with the view to finding the best working procedure for use in a mechanized press forge and to provide leads on the development of plant and techniques for automatic forging.

First, the shaping and manipulative actions that make up the process are described in general terms, by invoking the principle of geometrical similarity and with the aid of a semi-empirical rule about lateral spread. Next, the many conceivable working procedures are classified topologically and the class most conspicuous for economy of actions is identified. This is then examined with respect to the duration of the job, the required load capacity of the press, and the costs of production, for the type of plant in which not only shaping but also manipulation is fast and precise, and the two are properly synchronized. From this, working methods can be specified for maximum rate of output and for minimum cost, both absolutely and for a particular forge. There follows a discussion of the implications of the theory for plant development.

The principal conclusions are as follows:

1. Generally, the most efficient working procedures are those in which both squeeze and feed increments are progressively changed in proportion to the current height and width of the piece, so that its cross-section alternates between the square and one rectangular shape.

2. The most effective means of attaining high output rates is to employ throughout as large a reduction of the height of the piece as is compatible with requirements of product quality.

3. There is an optimum feed increment for each job and working rate of plant, which, together with the maximum squeeze, yields the cheapest working procedure at an output rate only slightly inferior to the maximum. If the plant consists of a modern fast-stroking press and a manipulator with a performance that matches that of the press, then this optimum is 50–100% larger than is in common use at present. Correspondingly, the load rating of the press needs to be larger.

4. The most urgent target for plant improvement is faster feeding of the piece in cogging passes and quicker manipulation between passes.

5. Research on tool design is desirable, with the object of raising the present limits on the reduction of height in a single squeeze. 1756

INTRODUCTION

THE WAY in which a forging is shaped is at present left to the on-the-spot judgment of the forgemaster. This is in marked contrast to associated processes, such as the heat-treatment and machining of forgings, which are prescribed in some detail. However, the idea of pre-planned forging is gaining support in some US forges and, judging by a recent Russian book on the design of heavy forges,[1] is already accepted in the USSR. Both US and Russian ideas seem to be tied to prevailing practice which may well have to be revised when the many changes of equipment now afoot find their way into forges. For this reason, a more fundamental approach to the problem seems desirable, with the object of evolving generally valid

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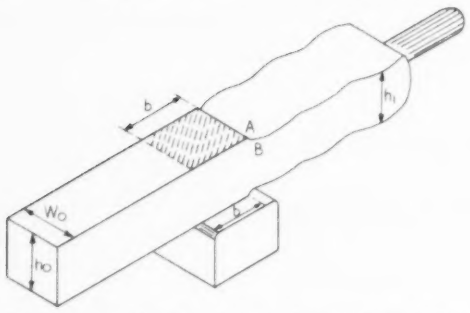
Dr Wistreich and Mr Shutt are respectively, Head of Mechanical Working Division and Scientific Officer in the Division.



1 *Elementary cogging step, the area of contact between the piece and the upper tool is shaded*

principles of programming and of providing guidance on the potentially most advantageous combinations of plant and working method.

In the present paper, these ideas are pursued for a particular forging process, namely the cogging of square blooms and billets by means of flat tools, and for the type of semi-automatic plant emerging from development in our laboratories.* This process was chosen because the mathematical difficulties of a theoretical analysis seemed least formidable in this case; for the same reason the analysis ignores the initial breakdown of the ingot shape and the final planishing of the product. Even so, the findings have potentially much wider uses, since cogging enters into the manufacture of the majority of forgings made in open dies.

Nature of problem

The function of press cogging is to reduce the size of the cross-section of an oblong piece; also, the shape of the final cross-section is quite frequently meant to be the same as the initial one. Since the piece is forged stepwise on account of its comparatively great length, the operation consists of numerous squeezes applied to portions of the piece and of in-between movements of the piece as a whole. In the interests of economy of movement and least distortion of surfaces, the squeezes are so arranged that the piece is uniformly reduced in height from end to end in what will be termed a 'pass'. Invariably, several passes are needed to accomplish the job; also, both pairs of faces have to be worked at one time or another because not only the height but also the width of the piece must be reduced.

Although, in principle, the number of ways in which this procedure might be carried out is infinite, the choice is restricted by considerations of product quality, plant performance, and the need to work in a limited range of elevated temperatures. Within these practical limits, the numbers, sizes, and sequences of squeezes and in-between movements can still be varied a great deal, and which combination is to be preferred will depend on how long it takes to complete the job and how large a plant it calls for. These issues, and their implications for further development will be considered in the main body of the paper, but first the technological bounds of the problem will be derived from what is known about deformation in the elementary working step of the operation.

* In essence, the plant consists of a fast-working press and rail-bound manipulator, the motions of which are interlocked and controlled with precision[2]

LIST OF SYMBOLS

h = height of stock
w = width of stock
ℓ = length of stock
b = bite = length of tool in contact with stock
$1/\gamma$ = squeeze ratio = $\dfrac{\text{height before compression}}{\text{height after compression}}$
β = spread ratio = $\dfrac{\text{width after compression}}{\text{width before compression}}$
λ = forging ratio in one pass = $\dfrac{\text{length after pass}}{\text{length before pass}}$
Λ = total forging ratio
θ = bite ratio = $\dfrac{b}{w}$
ϕ = shape factor = $\dfrac{h}{w}$
s = spread function, generally taken to be a function of θ only
m_n = number of strokes in nth pass
μ_n = number of strokes in nth cycle
M = total number of strokes in whole schedule
k = number of cycles in whole schedule
p = number of intermediate rectangular shapes in one cycle
L = forging load
Y = yield stress
A = area of contact of tool and stock
C = constraint factor
h_n = height at end of nth pass
w_n = width at end of nth pass
ℓ_n = length at end of nth pass
b_n = bite during nth pass
$(1/\gamma)_n$ = squeeze ratio during nth pass
β_n = spread ratio during nth pass
λ_n = forging ratio during nth pass
θ_n = bite ratio during nth pass
ϕ_n = shape factor at beginning of nth pass
s_n = spread function during nth pass
T = time to perform given schedule
S = rotation time per pass
R = output of plant
U = cost per ton produced

THEORY OF COGGING STEP

Spread law

Referring to Fig.1 which depicts the individual cogging step, the independent variables are the 'squeeze' $h_0—h_1$, and the 'bite' b. The resulting dimensional changes satisfy the requirement of volume constancy, which takes the general form:

$$(1/\gamma) = \beta.\lambda \quad \ldots\ldots(1)$$

where $1/\gamma$ denotes the 'squeeze ratio' h_0/h_1, β the 'spread ratio' w_1/w_0, and λ the forging ratio w_0h_0/w_1h_1, which is also a measure of the elongation of the piece. How much elongation is obtained from a squeeze compared with the amount of spread, has been the subject of concurrent investigations[3, 4] which suggest that, within the range of conditions of practical interest, this depends principally on the 'bite ratio' θ, which is the ratio of longitudinal to lateral dimensions of the initial area of contact between tool and piece (b/w_0 in Fig.1). This relation will be referred to as the 'spread law'. For the purpose of the present analysis the preferred form of the spread law is:

$$\beta = (1/\gamma)^s \quad \ldots\ldots(2)$$

and $s = \theta/(1 + \theta)$ $\ldots\ldots(3)$

Equation (3) is not entirely in accord with experimental results[3, 4] but its mathematical simplicity is most helpful in further analysis.

Local deformation

The above three equations specify the overall dimensional changes of the piece resulting from a pass. However, they ignore local distortions of the lateral faces of the piece, which arise as a consequence of the constraints imposed by friction between tools and stock and by the overhanging bulk of the piece. The form of distortion differs according to whether the cross-section of the piece is squat or slender; also, the larger the squeeze and bite ratios the more pronounced the distortion. This is why planishing is necessary, but judging by concurrent investigations[3] the distortion is of no consequence in cogging proper. More serious is the incidence of laps (AB in Fig.1); this seems to be governed by the height and abruptness of the step separating the forged from the unforged portion of the piece. The remedy for it is to round or even taper the tool edges and to keep the squeeze ratio within bounds. Insufficient is known about this effect at present to put a firm figure on the upper limit of the squeeze ratio; although the prevailing practice is to keep this below 1·2, it is thought that values as large as 1·4–1·5 might eventually be adopted with suitably tapered tool edges.

The factors responsible for surface distortion also cause the internal deformation to be non-uniform. Repeated working tends to iron out the variations, but one must guard against the deformation of the core of the piece not being sufficient to consolidate any initial central unsoundness. From investigations by Cook[5] it would appear that this danger is avoided if $b > h/3$.

If the cross-section is unduly slender, one courts the risk of rhombic distortion of the billet, which is difficult to correct. The slenderness is conveniently measured by the ratio of the height to the width of the piece and in what follows will be termed 'shape factor' ϕ. It also plays a part in the spread law[4] and the distortion of the lateral faces. Its effects are unimportant provided $\phi < 3/2$, say.

Technological bounds

The foregoing indicates that in the interests of soundness of product the squeeze and bite must be kept within bounds, the values of which depend on the shape of the tools and are not as yet known precisely. For the purpose of the present analysis we shall assume the following 'technological' bounds:

to avoid lapping $(1/\gamma) \leqslant 1{\cdot}3$

to avoid unsoundness of core $\theta > \phi/3$*

to avoid rhombic distortion $\phi \leqslant 3/2$

The first and third bounds may also, in some circumstances, give an upper bound on θ which is less than that imposed by the largest practical size of the tools.

Load

The load associated with a cogging step is:

$$L = YAC \qquad \ldots\ldots(4)$$

* Since $b/h = \theta w/h = \theta/\phi$

TABLE I Parameters of cogging schedules with 90° rotation after each pass

Parameter	Odd passes	Even passes
Squeeze ratio	$\frac{1}{\gamma_{2n-1}} = \frac{h_{2n-1}}{h_{2n-2}}$	$\frac{1}{\gamma_{2n}} = \frac{w_{2n}}{w_{2n-1}}$
Spread ratio	$\beta_{2n-1} = \frac{w_{2n-1}}{w_{2n-2}}$	$\beta_{2n} = \frac{h_{2n}}{h_{2n-1}}$
Bite ratio	$\theta_{2n-1} = \frac{b_{2n-1}}{w_{2n-2}}$	$\theta_{2n} = \frac{b_{2n}}{h_{2n-1}}$
Shape factor	$\phi_{2n-1} = \frac{h_{2n-1}}{w_{2n-2}}$	$\phi_{2n} = \frac{w_{2n-1}}{h_{2n-1}}$
No. of steps per pass	$n_{2n-1} = \frac{l_{2n-2}}{b_{2n-1}}$	$n_{2n} = \frac{l_{2n-1}}{b_{2n}}$

where Y is the yield stress of the material and A the area of contact between tool and piece, both taken at the end of the squeeze, and C is a 'constraint' factor to allow for the heterogeneity of deformation arising from the constraints exercised by tool friction and overhang of the piece. In the absence of experimental data, the following formulae for C will be used:

$$\begin{aligned} C &= 0{\cdot}797 + 0{\cdot}203\,\phi\gamma/\theta, \quad (\phi\gamma/\theta) > 1 \\ C &= 1 + \theta/4\phi\gamma, \qquad\qquad (\phi\gamma/\theta) < 1 \end{aligned} \qquad \ldots\ldots(5)$$

The first of these represents a straight-line fit of the appropriate data of Hill's indentation theory.[6] The second equation is based on Bishop's extension of the indentation theory,[7] modified to allow for the complete tool sticking which normally obtains in flat tool cogging; the equation is derived in Appendix I.*

In the present paper the absolute value of the load is of lesser interest than its relative change with squeeze and bite ratio, other factors remaining constant. For this purpose, the following formulae, derived from equations (4) and (5), are more useful:

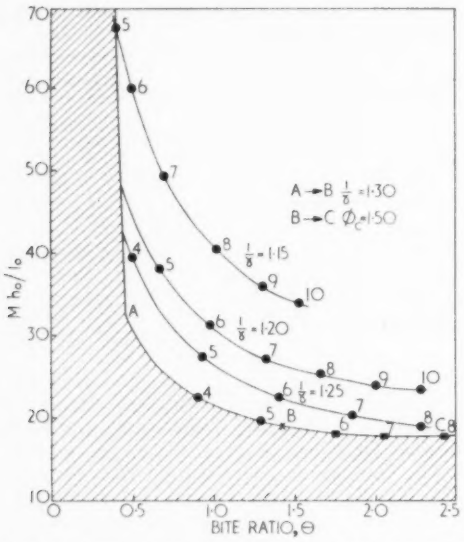
$$\begin{aligned} P &= L/Yh_0w_0 \\ P &= 0{\cdot}797\,(\theta/\gamma\phi) + 0{\cdot}203,\ \theta/\gamma\phi < 1 \\ P &= (\theta/\gamma\phi) + (\theta/2\gamma\phi)^2,\ \theta/\gamma\phi > 1 \end{aligned} \qquad \ldots\ldots(6)$$

THEORY OF COGGING SCHEDULES

To prescribe a particular cogging job in its entirety it would be necessary to list all the press and manipulator actions involved, in proper sequence and with full details of spatial positions. The latter depend on the dimensions of the piece at each stage and the squeeze and bite to be applied. They can be calculated with the aid of equations (1–3), pass by pass, for any chosen sequence. With this procedure, however, one does not know beforehand whether one will end up with the desired set of final dimensions of the piece and whether the program is practical. The purpose of the theory evolved in this part of the paper is to solve this difficulty; the theory does not deal with programs directly, but with 'schedules' which are more general concepts from which programs can be derived.

We define a schedule as follows: a cogging schedule comprises a finite sequence of squeeze ratios, a corresponding finite sequence of bite ratios, one of each per pass, and an assignment of successive passes

* In adapting the theory, the initial and not the final length of the tool contact has been used for reasons of mathematical expediency. The resulting error in the most unfavourable case in the present paper is only 6%.



2 *Number of strokes taken by dimorphous simple proportional schedules, the technological limits are shown and the area representing schedules which lie outside the technological limits is shaded*

to one or the other of the two pairs of oblong faces of the piece; which if employed in the order specified will impart the desired forging ratio and final shape factor to a rectangular prism with a specified initial shape factor.

This definition, together with the spread law and constant-volume law enables one to formulate the necessary equations from which the suitability of schedules can be assessed. To illustrate this, let us consider the case in which successive passes are performed on alternate pairs of faces. An even number of passes is then required, and the relevant parameters are given in Table I.

With the aid of these relations, two equations are then derived, one of which specifies the conditions as regards the cross-sectional shape and the other as regards the elongation of the piece. The equations are:*

$$\frac{\phi_{2k+1}}{\phi_1} = \prod_{i=1}^{k} \frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}} \qquad \ldots\ldots(7)$$

$$A = \prod_{i=1}^{2k} \gamma_i^{s_{i-1}} \qquad \ldots\ldots(8)$$

where A is the total forging ratio envisaged.

Taken together with the bounds stated in the introduction, these two equations specify all technologically admissible schedules of the type in which the piece is turned through 90° after each pass. Some of these schedules, of course, are of no operational interest: especially schedules involving an unduly large number of cogging steps. The total number of cogging steps associated with a particular schedule can be calculated from the equation (19II) derived in Appendix II. These have been computed for the case of square billets on the Pegasus computer for 18137 different combinations of arbitrarily chosen values of the variables and the 30 schedules with the least number of cogging steps were printed out. The method of calculation and the salient results are summarized in Appendix II. The main points of interest are:

(i) the 'best' schedule required little more than half as many steps as the 'worst' of the 30 'best' ones

(ii) an interchange of successive terms in the sequence of either $1/\gamma$ or θ values made a considerable difference to the number of steps.

Although, on the face of it, the number of schedules examined in this calculation is large, it is an insignificant fraction of the totality of potentially usable schedules, and a more efficient method of eliminating inferior schedules is required. Now, the second of the above-stated findings suggests that if schedules were grouped according to the patterns exhibited by the sequences of squeeze and bite ratios, the differences between some groups of schedules may be sufficiently large to eliminate entire groups from further consideration. Examples of sequence patterns are: uniformly ascending, varying cyclically, or constant values, of either squeeze or bite ratios, or of both.

Proportional schedules

The class of schedules of particular interest theoretically is that in which both squeeze and bite ratios are constant from beginning to end. Since this condition implies that press and manipulator motions in each pass bear fixed proportions to the current height and width of the piece, we shall speak of 'proportional' schedules.

The class may be further sub-divided according to the number of intermediate cross-sectional shapes (values of ϕ) assumed by the piece. The simplest sub-class is that in which the piece alternates between the square and only one rectangular shape and is turned through 90° after each pass or after each odd pass; let this be known as the group of 'dimorphous simple proportional' (DSP) schedules. The next sub-class is that having two intermediate rectangular shapes, i.e. three shapes including the square, and these are attained by working each pair of faces either twice over before turning to the other pair, or by turning after the second, sixth, . . . 2 $(n-1)$th pass; this is the group of 'trimorphous simple proportional' (TSP) schedules. Further sub-classes are readily specified by analogy.

It is a feature of SP schedules that the piece periodically reverts to the square shape, and the cycle consists of $2p$ passes, where p is the number of intermediate rectangular shapes.* It follows that the first basic schedule equation, which defines the condition about initial and final cross-sectional shapes (cf. equation (7)) is automatically satisfied so long as the number of passes in the entire cogging operation is an integral multiple of the cycle.

This property of automatic reversion to the square shape allows one to combine two or more SP schedules which either belong to different sub-classes or have different values of the squeeze and bite ratios, or both.

*See Appendix II for the derivation of the equations

* This can be deduced from equations (1–3) and the constancy of squeeze and bite ratios

We shall refer to these as 'compound' proportional (CP) schedules. In general, a CP schedule involves more intermediate shapes than the component SP schedule with the largest number of intermediate shapes. There is one exception to this rule, namely, the 'dimorphous CP' class which consists of two passes of a DSP schedule with an 'isomorphous SP schedule' for rectangles (rectangle–rectangle– . . .) sandwiched in between the two.

The second basic equation of SP schedules, which specifies the condition about total forging ratio, follows at once from definitions and previous equations:

$$\log A = \frac{2pk}{1+\theta} \log\left(\frac{1}{\gamma}\right) \quad \ldots\ldots(9)$$

where k is the number of cycles and $2\ p$ is the number of passes in a cycle.

DSP schedules

The number of cogging steps (M) in DSP schedules can be calculated from equation (19II), since a DSP schedule is a particular case of the general schedule considered in Appendix II. As shown there, the equation can be reduced to:

$$\frac{Mh_0}{\ell_0} = \frac{1}{\theta}\left(1 + A^{\frac{s-2}{2k(s-1)}}\right)\frac{A^{3/2}-1}{A^{3/2k}-1} \quad \ldots\ldots(10)$$

This function has been plotted in Fig.2 for $A=3$, from which it will be seen that the larger the squeeze and bite ratios, the fewer the number of cogging steps needed. The graph illustrates the further points that in the region of small bite ratios, small changes in either squeeze or bite ratio have a pronounced effect on the number of steps, and in the region of large bite ratios, a change in the squeeze ratio still has a large effect but the variation due to a change in the bite ratio is very small.

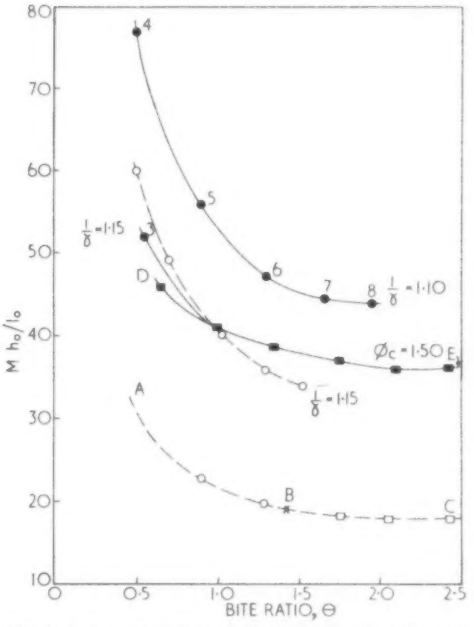
Since in DSP schedules the least number of cogging steps is associated with the combination of the largest permissible squeeze and bite ratios, it follows that even the 'best' general schedule of those calculated on the computer must be inferior to the DSP schedule based on the largest combination of $1/\gamma$ and θ occurring in the former. This is born out by the instance quoted in Appendix II. It follows, too, that CP schedules, other than the DCP schedule, are bound to involve more steps than the corresponding DSP schedule.

TSP schedules

The equation for the number of steps is derived in a manner analogous to that of equation (10). Noting that $p=2$ in this case, it is:

$$\frac{Mh_0}{\ell_0} = \frac{1}{\theta}\left(1 + A^{\frac{2s-1}{4k(s-1)}}\right)\left(1 + A^{\frac{s-2}{2k(s-1)}}\right)\frac{A^{3/2}-1}{A^{3/2k}-1} \quad \ldots\ldots(11)$$

which exhibits the same general trends as equation (10). The function is plotted in Fig.3 for comparison with DSP schedules. It will be noted that the ϕ-limit is reached at lower values of $1/\gamma$ and θ than in the case of DSP schedules. Comparing the two groups one sees that the most efficient DSP schedule is markedly superior to the most efficient TSP schedule and, generally, if large values of $1/\gamma$ can be employed the DSP schedules require substantially fewer strokes for the same $1/\gamma$ and θ; the TSP schedules are slightly better in the region of very small θ and $1/\gamma$ values.



The dashed curves refer to DSP schedules, the full curves to TSP schedules. ABC shows the technological limits on DSP schedules and DE shows the technological limits on TSP schedules.

3 *Number of strokes taken by trimorphous simple proportional schedules*

DCP schedules

In this class the shape sequence is square–rectangle–rectangle–. . . –rectangle–square, the piece being turned after each pass, and the bite ratio is constant throughout. It follows from considerations of symmetry and the spread law that the squeeze ratio can assume only two values, one for the first and ultimate passes, the other for the intermediate passes of the 'rectangle–rectangle' namely 'isomorphous' sequence. Moreover, it is readily shown that the first squeeze ratio is equal to the square root of the second. The second basic schedule equation is then, by analogy with equation (9):

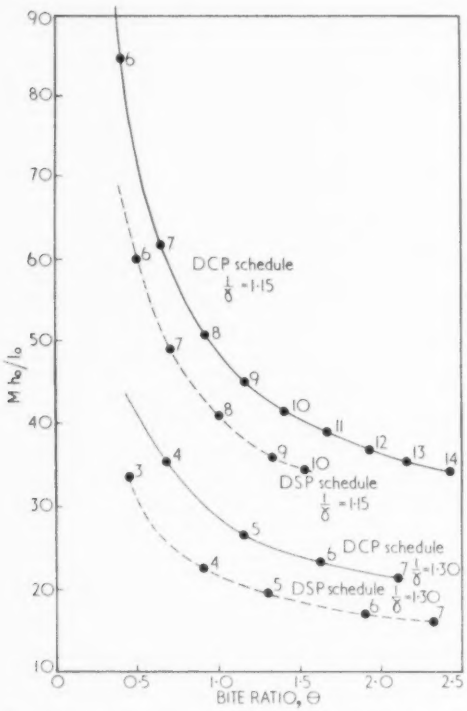
$$\log A = \frac{2k-1}{1+\theta} \log\left(\frac{1}{\gamma}\right) \quad \ldots\ldots(12)$$

The equation for the number of strokes is:

$$\frac{Mh_0}{\ell_0} = \frac{1}{\theta}\left\{1 + \left(\frac{1}{\gamma}\right)^{\frac{1}{2(1+\theta)}} A^{3/2} + \left[\left(\frac{1}{\gamma}\right)^{\frac{3\theta}{2(1+\theta)}} A^{3/2} - \left(\frac{1}{\gamma}\right)^{3/2}\right]\frac{\left(\frac{1}{\gamma}\right)^{\frac{2+\theta}{1+\theta}}+1}{\left(\frac{1}{\gamma}\right)^{\frac{3}{1+\theta}}-1}\right\} \quad \ldots(13)$$

where $1/\gamma$ is the squeeze ratio in the intermediate rectangle–rectangle sequence. Although this is a more complex function than those of the SP schedules so far considered, it exhibits a similar trend, the number of cogging steps decreasing with increasing squeeze and bite ratios.

The DCP and DSP schedules are compared in Fig.4



4 *Comparison of number of strokes taken by dimorphous simple proportional schedules and dimorphous compound proportional schedules*

for $A = 3$ and two values of the squeeze ratio. This illustrates the point that the DSP schedule group always requires fewer cogging steps in comparable conditions.

The indications of the foregoing analysis are that no matter what the details of the working procedure, it is desirable to employ the largest allowable squeeze and bite ratios in each pass in the interests of reducing the number of cogging steps to the minimum. Furthermore, the group of dimorphous simple proportional schedules is, in this respect, potentially superior to any other conceivable class, firstly, because it enables one to use the largest possible squeeze ratio for any given bound on the slenderness of rectangular shapes and secondly, because this value of squeeze ratio and a correspondingly large value of the bite ratio is maintained in all passes.

The issue is not as clear-cut in the range of small bite and squeeze ratios. Indeed, for values dominating much of current industrial practice,* DSP schedules may even be slightly inferior. However, even within this range the DSP schedules have the advantage of simplicity, which is particularly useful when translating schedules into specific programs; indeed, they lend themselves to automatic programming systems which are self-correcting in respect of deviations from the postulated spread law.†

* Say $\theta < 0{\cdot}5$, especially on large presses, and $1/\gamma \approx 1{\cdot}15$.

† One such system is the subject of a patent application.

OPERATIONAL ASSESSMENT

We shall now seek to establish which are the best schedules for use in the forge. For this purpose, the factors to be considered are: the time taken to complete the job, the press capacity, and the cost of the job. We shall concentrate on the DSP schedules for the reasons just stated.

Fastest schedule

The time to complete a cogging job depends not only on the number of cogging steps but also on the number of passes, on account of re-positioning and turning between passes. Since, as shown earlier, M varies inversely and k directly with θ, there must be a quickest way of completing a given cogging job.* Naturally, this also depends on the operating characteristics of the plant; these will be discussed in detail later on. For present purposes a somewhat simplified mathematical model of plant operation will be specified, with reference to the following practical considerations:

(i) the stroke rates of modern presses vary inversely, and quite appreciably, with penetration[8]

(ii) it should be feasible to design a manipulator capable of keeping up with the press, so long as the largest bite is not unduly large compared with the penetration

(iii) the time taken up by interpass rotation and height adjustment varies, no doubt, with the current cross-sectional dimensions of the piece; however, in most cogging operations the variation is probably small enough to be neglected.

Let us then assume that the duration of the cogging step is $Ah(1-\gamma)$, where A is a constant characteristic of the plant, and h the dimension to be squeezed; and that the time for interpass manipulation S is also a constant. Confining ourselves for the moment to those DSP schedules in which consecutive passes are started from opposite ends of the piece and this is turned after each pass, the time to complete the schedule is:

$$T = \frac{2A\,l_0\,(A-1)\,(1-\gamma)}{\theta\left(\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}-1\right)} + S\,\frac{1+\theta}{\log\left(\frac{1}{\gamma}\right)}\log A \qquad \text{.....(14)}$$

The equation is derived in Appendix III, where it is also shown that the function has a minimum for a θ, the value of which increases with A and $1/\gamma$, and also with the initial length of the piece. One also notes that the longer the interpass manipulating time S in relation to the cogging rate of the plant (as defined by A), the smaller the optimum value of θ.

To illustrate these trends, the time function has been calculated for the case of pieces initially 4 ft long and cogged to 12 ft in a plant with a working rate of 84 one-inch penetration strokes per minute and an interpass manipulation time of 3 s. The data are plotted in Fig.5 for two squeeze ratios; the figure also contains curves (shown dashed) for a manipulation time of 6 s, to draw attention to the importance of the

* That is, if both are continuous functions. If the requirement that k must be an integer is taken into account, then it is possible to have two equally fast schedules, faster than any other ones.

interpass manipulation time for the overall time, for the value of the optimum bite ratio, and for the effect of the bite ratio on the time rating of the schedule.

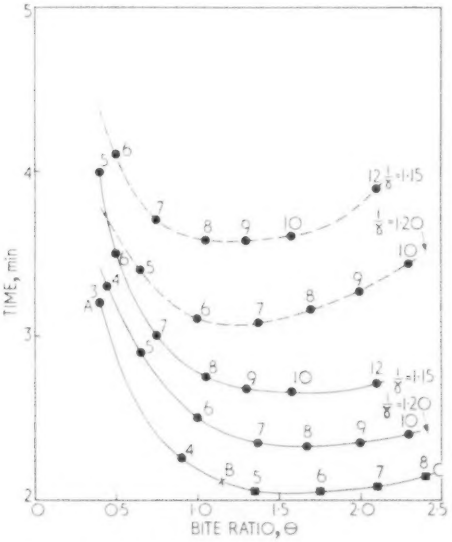
The fastest schedule defined by equation (14) can be improved upon by omitting rotation of the piece after even passes, which is permissible in DSP schedules. This reduces the second term in equation (14) by a factor of between 0·5 and 1·0, and accordingly increases the optimum value of the bite ratio.

If all passes have to be started from the same end of the piece, then a further term must be added to the time function to allow for full traverse of the piece between passes. The term is derived in Appendix III and its implications for manipulator design are discussed in a later part of the paper. Here it will suffice to note that in addition to lengthening the overall time it lowers the value of the optimum bite ratio.

Consideration of forging load

We shall now examine the effect of the forging load on the choice of schedule for a press of given load capacity and, conversely, the implications of the foregoing analysis for the choice of press capacity. First, however, we must ascertain at which stage of the cogging operation the peak load is most likely to occur.

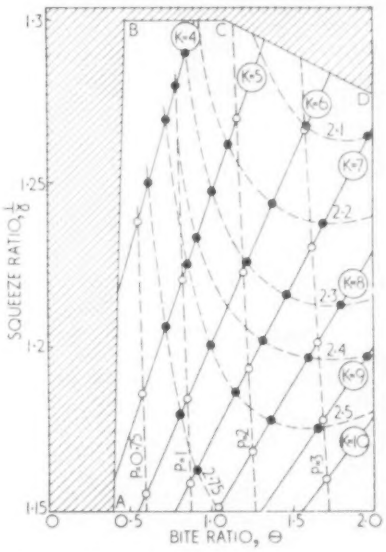
In the odd-numbered passes, the area of contact between tool and stock is larger than it is in the even passes. At the same time, the changes in yield stress and constraint factor between an odd pass and the succeeding even pass are small. The net result is that the load is always greater in an odd pass than it is in the following even pass. Since geometrical similarity is preserved at the beginning of each odd pass of a proportional schedule, the constraint factor is the same for all the odd passes and can be omitted from further consideration. The area of contact is roughly



Parameters: $\ell_0 = 4$ ft $\quad A = 3$
Press speed = 84 one-inch penetrations/min

The full curves have an interpass manipulation time of 3 s, the dashed lines have an interpass manipulation time of 6 s

5 *Time taken by dimorphous simple proportional schedules*



—●— constant time lines
—○— constant load lines
—— solution of schedule equation for $A = 3$

ABCD is the boundary of the technologically admissable area. AB $-\theta = \phi/3$, BC $-1/\gamma = 1{\cdot}3$, and CD $-\phi = 15$

6 *Time/load chart for dimorphous simple proportional schedules*

equal to $w_0^2\theta$ in the first odd pass and $w_0^2\theta/A$ in the last odd pass, so that the ratio of initial to final areas of contact is approximately equal to the total forging ratio A.

It follows then, that if the yield stress at the end is less than A times the yield stress at the commencement of forging, then the largest load occurs in the first pass. The yield stress, of course, increases during forging, principally because the piece gets colder. How great the temperature drop, depends on the time taken and the size of the piece, and will therefore vary with circumstances. Taking the case of a low-carbon steel worked between 1200° and 900°C, the yield stress increases by a factor of about 2·3.[9] If the forge in question works at speeds comparable with those used in plotting Fig.5, forging ratios considerably in excess of 3 can be obtained in the time in which a billet initially as small as 8-in. square cools down from 1200° to 900°C. It seems, therefore, that in a forge consisting of a fast-acting press and manipulator the largest load occurs in the first pass. Calculations of the load used on each pass of a variety of DSP schedules support this conclusion.

'Optimum' press size

The size of press required for any job and schedule can now be calculated from equation (6). The existence of an 'optimum' press size for a given job, in terms of output rate, can be demonstrated as follows.

Since the peak load increases monotonically with bite ratio for a given squeeze ratio (cf. equation (6)), the press capable of delivering the peak load associated with the optimum bite ratio will accomplish the job more quickly than any smaller press; any

TABLE II Comparison of schedules with load ceilings

Press size	Optimum	Sub-optimal	
Type of schedule	Fastest DSP	Fastest DSP	Two-tier DP
Forging ratio	9	9	3×3
Squeeze ratio, $1/\gamma$	1·3	1·3	1·3
Bite ratio, θ	1·4	0·9	0·9/1·4
No. of passes, 2k	20	16	18
Peak load, tons	4 430	2 950	2 950/2 950
Pass time, min	6·2	7·4	6·5
Interpass time, min	1·0	0·8	0·9
Total time, min	7·2	8·2	7·4

larger press cannot improve on this performance since, by definition, the optimum bite ratio provides the fastest schedule; *ipso facto*, if worked according to the fastest schedule, any larger press will be underemployed.

Fixed press capacity

Equation (6) can also be used to find the largest squeeze and bite ratios on a given press, by regarding the term P as the press capacity factor for the job in question (note that $\phi=1$ in this case). Curves of constant P have been plotted in Fig.6, together with curves of constant T, for use in locating the fastest schedule for a given press capacity.

Fastest schedule for sub-optimal press

Figure 6 suggests that a schedule only slightly slower than the fastest can be accomplished on a press of appreciably smaller capacity than the 'optimum' just defined. However, when large forging ratios are involved, the loss in output rate may be more pronounced.* In this case, the loss can be partly retrieved by means of a compound schedule, consisting of two or more DSP sequences with identical peak loads and squeeze ratios, the last of which is based on the optimum bite ratio.

The principle of this compounding scheme and its benefits are illustrated by the following example: suppose a 36 ft long 8 in.×8 in. billet is to be made from a piece initially 4 ft long and with an initial yield stress of 2·9 tons/in², on a plant with a load capacity of 3000 tons and having the cogging rates and interpass manipulation time specified earlier; compare the fastest DSP schedule attainable on this plant with the fastest compound schedule consisting of two DSP sequences of equal forging ratios. The problem is worked out in Appendix IV and the results are set out in Table II.

Not only is the compound schedule faster than the fastest DSP schedule obtainable on the press in question but it is nearly as fast as the very fastest schedule associated with the optimum press. One wonders, consequently, whether compound schedules might not be generally preferable to DSP schedules when the job has to be done on a sub-optimal press and whether more elaborate compounding would be even more advantageous. Unfortunately, the scope for compounding in this manner is limited because the smaller the forging ratio of the component sequence the wider apart are spaced the admissible θ values for any one squeeze ratio. For instance, in the example just considered, a 'three-tiered' schedule is not realizable on the press in question save with a smaller squeeze ratio in the middle sequence, as a consequence of which the total time exceeds that of the 'two-tier' schedule.

Cheapest schedule

The scheduling theory can also be used to determine the DSP schedule for which the forging costs are least. In general, this must be slower than the fastest schedule, as is shown by the following argument about marginal costs.

Imagine a series of forging plants identical in all respects save one, namely the load capacity of the press, and let them be engaged on one and the same job, each working at full occupancy and maximum output rate The cost of cogging per piece is $U=(A+B)\,T$, where A varies with press size and B does not, and T is the time per billet according to equation(14). If the squeeze ratio is kept constant, then U is a function of θ only. In the stated circumstances, A is a monotonically increasing function of θ (cf. equation (6) and T passes through a minimum for an intermediate value of θ (cf. equation (14)). Differentiating U with respect to θ and equating the differential to zero, the necessary condition for U to be at a minimum is $\mathrm{d}T/\mathrm{d}\theta=-(\mathrm{d}A/\mathrm{d}\theta)\,T/(A+B)$. Now T, A, and B, are always positive, and so is $\mathrm{d}A/\mathrm{d}\theta$ by definition. Consequently, $\mathrm{d}U/\mathrm{d}\theta=0$ when $\mathrm{d}T/\mathrm{d}\theta<0$. Since the latter occurs when the bite ratio is smaller than the optimum, it follows that the cheapest schedule is slower than the fastest schedule and the plant with the lowest cogging cost per piece is 'sub-optimal', that is smaller than the plant with the highest output rate.

The function $U(\theta)$ can be combined with the inverse of the function $T(\theta)$ to provide a cost/output curve for any particular job and set of operational characteristics of the forging plant. An example of this has been worked out with the aid of rudimentary cost data and plotted in Fig.7. Two sets of curves are shown for two levels of occupancy of the plant, for a squeeze ratio of 1·15 and the maximum permissible squeeze ratio respectively; all the curves are based on DSP schedules.

Figure 7 emphasizes that the difference of output rate between the points of maximum output rate and of minimum cost diminishes rapidly with a drop in occupancy. Since in practice a 100% occupancy is not realizable, one concludes that the cheapest schedule is, to all intents and purposes, the best all-round schedule.

Effect of heating costs

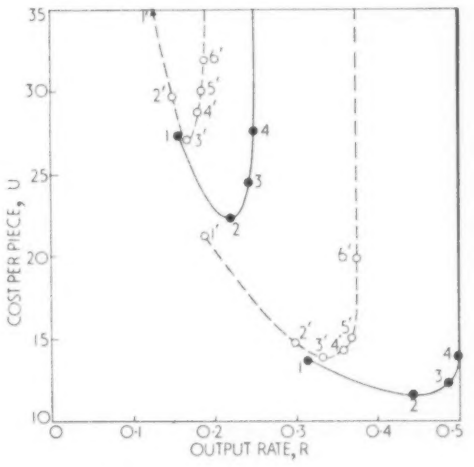
Although not within the scope of the paper, the heating procedure cannot be ignored when planning the cogging operation, owing to the strong technological and operational couplings of the two processes. Not only does the amount of heat required depend on the time taken by the cogging, the size of the piece, the forging ratio, and the starting temperature, but the choice of the cogging time will be influenced by the metallurgical requirement for the finishing temperature to be below a specified figure, and by the effect

* The T-curves in Fig.6 are plotted for $A=3$. The rate of change of T with θ for bite ratios smaller than the optimum is roughly proportional to $A-1$ (cf. equation 14).

of temperature on yield stress. Furthermore, owing to the markedly different time rates of the heating and forging processes, the foregoing technological considerations will need to be further trimmed by operational factors of the forge in question, which are all the more important since heating costs are of the same order of magnitude as cogging costs.

On present practice alone, in which the piece is heated and reheated to the same upper limit, the main effect of heating costs on the choice of the most economical schedule is to single out for preference those schedules which can be completed in an integral number of heats, inasmuch as each reheat represents a substantial and finite addition to the production cost of the piece. Thus, the effect could be allowed for by introducing into the equations a condition which would be formally analogous to the condition about the number of pass cycles k being an integer. Recalling, however, that the emphasis of the present analysis is on methods and equipment well in advance of established practice, and noting that the 'best' schedules here considered may substantially cut down the quantity of heat required, this approach seems hardly worthwhile.

It seems to us that for reasons of fuel economy as well as to bring the time rates of the two processes into better harmony, future heating procedures are likely to be more flexible as regards both starting temperature and the amount of heat put into the piece at one go. In other words, the heating procedure will be fitted to the cogging operation rather than the other way round, as at present. If this forecast is correct, then the effect of heating costs on the choice of the most economical cogging schedule will be of second order only and need not be further considered in the context of the present paper.



Value of P, θ, and $1/\gamma$ corresponding to the numbered points

Point	P	θ	$1/\gamma$	Point	P	θ	$1/\gamma$
1	0·64	0·42	1·3	1′	0·43	0·25	1·15
2	1·51	0·9	1·3	2′	0·71	0·55	1·15
3	1·57	1·37	1·3	3′	0·89	0·75	1·15
4	4·09	1·93	1·3	4′	1·52	1·02	1·15
				5′	2·00	1·27	1·15
				6′	1·58	1·55	1·15

7 *Relation between cost and output. The lower two curves are for 100% occupancy, the upper two curves are for 50% occupancy.*
Points 1 and 2′ are the schedules using the smallest press within the technological bounds assumed in the paper. Point 1′ shows a schedule which, although outside the technological bounds, is close to present practice. Output rate and cost per piece are in arbitrary units

IMPLICATIONS FOR PLANT DEVELOPMENT

On the strength of the present analysis, the load rating of future presses ought to be higher than at present, so as to take advantage of the improvement of output rate with bite ratio. Just how substantial the increase should be, will depend on the relation between inter-pass manipulation time and pass cogging rate and on the capital costs of the power unit relative to those of the press and manipulator structure.

No increase in press crosshead speeds need to be envisaged until manipulation is very substantially improved. Indeed, one might well examine the merits of slower stroking rates coupled with higher load ratings. Since this view is in conflict with recent trends of development,[10] it seems desirable to enlarge on the reasons for it.

During a cogging pass on a properly synchronized combination of press and manipulator, the manipulating time corresponds to the idle portion of the press stroke cycle and should be short in the interests of greatest utilization of the press, which is the more costly component of the forging plant. For the purpose of the present argument, this time is conveniently stated as

$$t_m = \theta h/\phi \bar{v}_m \quad \ldots\ldots(17)$$

where $\bar{v}_m$ is the mean velocity of the manipulator during stepwise advance.* Assuming that the distance travelled by the press crosshead during the remainder of the press stroke cycle bears a fixed ratio to the squeeze, this time is:

$$t_p = a(1-\gamma)h/\bar{v}_p \quad \ldots\ldots(18)$$

where a is a constant and $\bar{v}_p$ is the 'mean' crosshead speed defined by analogy with $\bar{v}_m$. To the first order of approximation, the two representative velocities can be taken as independent of stock height, particularly if we now confine ourselves to a narrow range of stock dimensions.

From the previous section, the schedule parameters appearing in the two equations may be taken as constant. Consequently, the effective stroke rate of the press, which is the inverse of the time of the complete stroke cycle $(t_p + t_m)$, is

$$N = \bar{v}_p \Big/ \left(c + d\frac{\bar{v}_p}{\bar{v}_m}\right) \quad \ldots\ldots(19)$$

where c and d are suitable constants. Equation (19) shows that the effect of a change in crosshead speeds

* The formal definition of it is $\bar{v}_m = \frac{1}{t_m}\int_{t_m} v_m dt$ where the integral is the Lebesque integral

on the stroke rate depends on the relative magnitude of the two terms in the denominator. To illustrate the point, data on a modern 3000-ton forging press quoted by Elkan and Lewis[10] have been manipulated on the basis of some plausible assumptions about c and d. The specified working rate of this press when cogging with 2-in. squeezes is 30/min. If all crosshead speeds were doubled, then the working rate would increase by 18%; doubling either the penetration speed alone or the approach and release speeds alone would raise the working rate by 8%. In contrast with this, a doubling of the 'representative' manipulating speed would increase the working rate by 33% without any change in the press crosshead speeds, or the latter could be almost halved without affecting the working rate.

The last figures tellingly illustrate the desirability of quick stepwise manipulation in a cogging pass. No less important is interpass manipulation, as demonstrated by the curves in Fig.5; from experience with the BISRA experimental forge, the need is for elimination of delays between successive actions rather than for faster rotation and hoisting movements. The analysis in the previous section and Appendix III also conveys the marked superiority of a manipulator capable of cogging equally well whether advancing or retreating over one that must be used only 'on the retreat'. The difference is, of course, determined by the nature of the peel action during the release of the piece by the press tools, and this should be given close attention by manipulator designers.

Throughout this paper, a complete interlocking of press and manipulator controls has been taken for granted and it has been further assumed that the manipulator and press characteristics are so matched that the working rate of the unit when cogging according to a particular DSP schedule, is strictly proportional to the reciprocal of the current size of the piece. Referring to equations (17) and (18), this implies that the 'representative' velocities of the two machines are independent of the size of the piece. In the case of the press, this is very nearly true because of the high crosshead accelerations and short action delay times of modern presses. Not so with present-day manipulators, in which the greater portion of the stepwise advance is taken up by acceleration and deceleration and, indeed, a steady speed is probably never attained in the latter passes of a cogging job when the bite is comparatively short. Assuming, however, that a part of the bite is traversed at a steady speed, the time for the complete bite is $t=\theta h/\phi v+v/f$, where v is the steady speed and f the acceleration. It follows that even if the manipulator performance is well matched to that of the press at the start of a cogging operation, it will lag behind towards the end and thereby impair the performance of the combined plant, unless the second term in this time function is made small relative to its first term. The function helps one to set a suitable target for the manipulator performance, e.g. one might aim at $f=5v^2/h$ which, with $\theta\approx 1$ and $\phi=1$ and a total forging ratio of, say, $A=4$, would maintain the match of press and manipulator performances within 10%. An even higher numerical factor would enable the matching to be maintained over a wider range of jobs.

Finally, in order to take advantage of the superiority of proportional schedules, the controls of both press-crosshead movement and manipulator traverse should include means of automatic reference of position displacement to the current height and width of the piece.

CONCLUSIONS

The theory demonstrates the advantages of relating squeeze and bite to the current height and width of the piece, and it provides means for determining the best values of these for any set of circumstances.

Whatever the job and plant, it is advantageous to apply the largest squeeze that can be tolerated without risk of surface lapping, rhombic distortion, or buckling in the subsequent pass. The choice of the bite for a particular job is dictated by the load capacity of the press and by the need to strike the right balance between the numbers of cogging steps and of passes, which varies with plant characteristics.

The theory adds support to what is already known about the desirability of faster manipulation in the interest of making full use of the press which is the most costly component of the plant. It also poses the further requirement of accurate control of manipulator feed. Once these needs are satisfied, the load rating of presses will need to be raised if one is to realize the large improvement of the efficiency of the cogging operation which the analysis shows to be possible.

The more efficient the working procedure and the quicker, in consequence, the completion of the job, the greater is the need for flexibility of heating and the more important it is to eliminate time delays in transporting the piece between furnace and press. These aspects of forging call for intensive study in addition to research on cogging tools aimed at raising the present ceiling on the squeeze ratio.

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APPENDIX I

THE CONSTRAINT FACTOR IN THE STICTION CASE FOR $(\gamma\phi/\theta) < 1$

Suppose a bar of height h and width w is indented by a tool of length b. We consider the plane strain case and take the origin of coordinates at the centre of the impression with x axis along the axis of the bar.

Let p be the normal pressure on the upper and lower faces of the bar and q the horizontal stress parallel to the x axis. We take as yield criterion

$$p - q = Y \quad \ldots\ldots(1\text{I})$$

where $Y/2$ is the yield stress in shear.

By considering the equilibrium of an elementary section, of thickness dx, perpendicular to the x axis and assigning a constant frictional force of magnitude $Y/2$ along the surface of contact in a direction such as to oppose the flow, we have

$$h\,dq + Y\,dx = 0 \quad \ldots\ldots(2\text{I})$$

Eliminating q gives

$$\frac{dp}{dx} = \frac{-Y}{h} \quad \ldots\ldots(3\text{I})$$

and solving this with the boundary conditions $p = Y$ at $x = b/2$ we obtain

$$p = Y\left(1 + \frac{b}{2h} - \frac{x}{h}\right) \quad \ldots\ldots(4\text{I})$$

Integrating this expression for p over the whole surface of contact gives

$$L = Yw\left(b + \frac{b}{4h}\right) \quad \ldots\ldots(5\text{I})$$

which gives the constraint factor

$$C = 1 + \frac{b}{4h}$$

(For a fuller discussion of this topic, *see* Bishop's paper.[3])

Now

$$\frac{b}{h} = \frac{\theta w_0}{h_0\gamma} = \frac{\theta}{\phi\gamma} \quad \ldots\ldots(6\text{I})$$

and so

$$1 + \frac{b}{4h} = 1 + \frac{\theta}{4\gamma\phi} \quad \ldots\ldots(7\text{I})$$

The area of contact between tool and piece is given by

$$A = b'w_1 \quad \ldots\ldots(8\text{I})$$

where b' is the length of contact at the end of the squeeze. Hence

$$A = bw_0\lambda\beta$$
$$= w_0^2\,\theta\lambda\beta$$

$$\text{i.e. } A = \frac{w_0^2\theta}{\gamma} = \frac{h_0 w_0\theta}{\gamma\phi} \quad \ldots\ldots(9\text{I})$$

From equations (8I) and (7I) equations (6) in the text are easily derived.

APPENDIX II

DERIVATION OF THE PRINCIPAL FORMULAE OF SCHEDULING THEORY

The schedule equations

We have

$$\phi_{2n+1} = \frac{h_{2n}}{w_{2n}} \quad \ldots\ldots(1\text{II})$$
$$= \frac{h_{2n-2}}{w_{2n-2}}\,\frac{\beta_{2n}\,\gamma_{2n-1}}{\beta_{2n-1}\,\gamma_{2n}}$$
$$= \phi_{2n-1}\frac{\beta_{2n}\,\gamma_{2n-1}}{\beta_{2n-1}\,\gamma_{2n}}$$

But $\gamma_n^{-s_n} = \beta_n$ for all n and so

$$\phi_{2n+1} = \phi_{2n-1}\frac{\gamma_{2n-1}^{1+s_{2n-1}}}{\gamma_{2n}^{1+s_{2n}}}$$

Hence after n similar steps

$$\phi_{2n+1} = \phi_1 \prod_{i=1}^{n} \frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}}$$

$$\text{i.e. } \frac{\phi_{2k+1}}{\phi_1} = \prod_{i=1}^{k} \frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}} \quad \ldots\ldots(2\text{II})$$

We have

$$A = \frac{\ell_{2k}}{\ell_0} \quad \ldots\ldots(3\text{II})$$
$$= \frac{\ell_{2k}}{\ell_{2k-1}} \times \frac{\ell_{2k-1}}{\ell_{2k-2}} \times \ldots\ldots\ldots\ldots \times \frac{\ell_2}{\ell_1} \times \frac{\ell_1}{\ell_0}$$
$$= \prod_{i=1}^{2k} \lambda_i \quad \ldots\ldots(4\text{II})$$

But $\gamma^{-s} = \beta$ and $\gamma\beta\lambda = 1$
i.e. $\lambda = \gamma^{s-1}$

$$\text{hence } A = \prod_{i=1}^{2k} \gamma_i^{s_i - 1} \quad \ldots\ldots(5\text{II})$$

The formula for total number of strokes in a schedule

We have

$$m_{2n} = \frac{\ell_{2n-1}}{h_{2n}} = \frac{\ell_0 \prod_{i=1}^{2n-1} \lambda_i}{\theta_{2n}\,h_{2n-1}} \quad \ldots\ldots(6\text{II})$$

$$m_{2n-1} = \frac{\ell_{2n-2}}{h_{2n-1}} = \frac{\ell_0 \prod_{i=1}^{2n-2} \lambda_i}{\theta_{2n-1}\,w_{2n-2}} \quad \ldots\ldots(7\text{II})$$

$$m_{2n-2} = \frac{\ell_{2n-3}}{h_{2n-2}} = \frac{\ell_0 \prod_{i=1}^{2n-3} \lambda_i}{\theta_{2n-2}\,h_{2n-3}} \quad \ldots\ldots(8\text{II})$$

Hence

$$\frac{m_{2n}}{m_{2n-1}} = \frac{\lambda_{2n-1}\,\theta_{2n-1}\,w_{2n-2}}{\theta_{2n}\,h_{2n-1}} \quad \ldots\ldots(9\text{II})$$

and

$$\frac{m_{2n-1}}{m_{2n-2}} = \frac{\lambda_{2n-2}\,\theta_{2n-2}\,h_{2n-3}}{\theta_{2n-1}\,w_{2n-2}} \quad \ldots\ldots(10\text{II})$$

which give

$$\frac{m_{2n}}{m_{2n-1}} = \frac{\lambda_{2n-1}\,\theta_{2n-1}}{\theta_{2n}\,\phi_{2n-1}\,\gamma_{2n-1}} \quad \ldots\ldots(11\text{II})$$

$$\text{and } \frac{m_{2n-1}}{m_{2n-2}} = \frac{\lambda^2_{2n-2}\,\theta_{2n-2}\,\phi_{2n-1}\,\gamma_{2n-2}}{\theta_{2n-1}} \quad \ldots\ldots(12\text{II})$$

TABLE III A selection of results for various schedules

	Schedule 1, $k=2$	2, $k=2$	3, $k=2$	4, $k=2$	5, $k=3$	6, $k=3$
$1/\gamma_1$	1·333	1·6	1·143	1·6	1·143	1·143
$1/\gamma_2$	1·6	1·6	1·333	1·333	1·143	1·333
$1/\gamma_3$	1·6	1·333	1·6	1·143	1·333	1·333
$1/\gamma_4$	1·34	1·34	1·408	1·391	1·333	1·333
$1/\gamma_5$					1·333	1·333
$1/\gamma_6$					1·344	1·152
θ_1	1	1	1	0·6	0·96	0·96
θ_2	1	1	0·6	0·6	0·96	0·96
θ_3	1	1	0·6	0·6	0·96	9·06
θ_4	0·884	0·884	0·444	0·554	0·96	0·96
θ_5					0·96	0·96
θ_6					0·793	0·7
No. of strokes	30·67	32·19	50·24	55·19	35·04	37·73

From equations (11II) and (12II) it follows by induction

$$m_{2n-1} = \frac{\ell_0}{h_0} \frac{\prod_{i=1}^{2n-2} \lambda_i \prod_{i=1}^{n-i} \lambda_{2i} \prod_{i=1}^{n-1} \gamma_{2i}}{\theta_{2n-1} \prod_{i=1}^{n-1} \gamma_{2i-1}} \phi_{2n-1} \quad \text{.....(13II)}$$

and

$$m_{2n} = \frac{\ell_0}{h_0} \frac{\prod_{i=1}^{2n-1} \lambda_i \prod_{i=1}^{n-1} \lambda_{2i} \prod_{i=1}^{n} \gamma_{2i}}{\theta_{2n} \prod_{i=1}^{n-1} \gamma_{2i-1}} \quad \text{.....(14II)}$$

By adding equations (13II) and (14II) we obtain:

$$\mu_n = \frac{\ell_0}{h_0} \left\{ \prod_{i=1}^{2n-2} \lambda_i \prod_{i=1}^{n-1} \left(\frac{\gamma_{2i} \lambda_{2i}}{\gamma_{2i-1}} \right) \left(\frac{\phi_{2n-1}}{\theta_{2n-1}} + \frac{\lambda_{2n-1}}{\theta_{2n} \gamma_{2n-1}} \right) \right\} \text{...(15II)}$$

Now

$$\phi_{2n-1} = \phi_1 \prod_{i=1}^{n-i} \frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}}$$

and so

$$\mu_n = \frac{\ell_0}{h_0} \left\{ \prod_{i=1}^{2n-2} \lambda_i \prod_{i=1}^{n-1} \left(\frac{\lambda_{2i} \lambda_{2i}}{\gamma_{2i-1}} \right) \left(\frac{\phi_1}{\theta_{2n-1}} \prod_{i=1}^{n-1} \left(\frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}} \right) + \frac{\lambda_{2n-1}}{\theta_{2n} \gamma_{2n-1}} \right) \right\} \text{.....(16II)}$$

But

$$\mu_n = \frac{\ell_0}{h_0} \left\{ \prod_{i=1}^{2n-2} \gamma_i^{s_{i+1}} \prod_{i=1}^{n-1} \left(\frac{\gamma_{2i}^{s_{2i}}}{\gamma_{2i-1}} \right) \left(\frac{\phi_1}{\theta_{2n-1}} \prod_{i=1}^{n-1} \left(\frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}} \right) + \frac{1}{\theta_{2n} \gamma_{2n-1}^{2-s_{2n-1}}} \right) \right\} \text{.....(17II)}$$

and since $M = \sum_{n=1}^{k} \mu_n$ .....(18II)

$$M = \frac{\ell_0}{h_0} \sum_{n=1}^{k} \left\{ \prod_{i=1}^{2n-2} \gamma_i^{s_{i-1}} \prod_{i=1}^{n-1} \left(\frac{\gamma_{2i}^{s_{2i}}}{\gamma_{2i-1}} \right) \left(\frac{\phi_1}{\theta_{2n-1}} \prod_{i=1}^{n-1} \left(\frac{\gamma_{2i-1}^{1+s_{2i-1}}}{\gamma_{2i}^{1+s_{2i}}} \right) + \frac{1}{\theta_{2n} \gamma_{2n-1}^{2-s_{2n-1}}} \right) \right\} \text{.....(19II)}$$

In the DSP schedule in which $1/\gamma$ and θ are constant for each pass equation (2II) is satisfied identically and equation (5II) reduces to:

$$\Lambda = \gamma^{2k(s-1)} \quad \text{.....(20II)}$$

whilst equation (19II) reduces to:

$$M = \frac{\ell_0}{h_0} \sum_{i=1}^{k} \left\{ \gamma^{(2n-2)(s-1)+(n+1)(s-1)} \left(\frac{\phi_1}{\theta} + \frac{1}{\theta \gamma^{2-s}} \right) \right\}$$

$$= \frac{\ell_0}{h_0 \theta} (\phi_1 + \gamma^{s-2}) \sum_{i=1}^{k} \gamma^{(s-1)(3n-3)} \quad \text{.....(21II)}$$

This series is a geometrical progression and may be summed to give:

$$M = \frac{\ell_0}{h_0 \theta} (\phi_1 + \gamma^{s-2}) \frac{\gamma^{3k(s-1)} - 1}{\gamma^{3(s-1)} - 1} \quad \text{.....(22II)}$$

Now, as shown above

$$\Lambda = \gamma^{2k(s-1)}$$

hence

$$\gamma^{3k(s-1)} = \Lambda^{3/2}$$

$$\gamma^{3(s-1)} = \Lambda^{3/2k} \quad \text{.....(23II)}$$

and

$$\gamma^{s-2} = \Lambda^{\frac{s-2}{2k(s-1)}}$$

Substituting equations (23II) into (22II) gives

$$M = \frac{\ell_0}{h_0} \left(\phi_1 + \Lambda^{\frac{s-2}{2k(s-1)}} \right) \frac{\Lambda^{3/2} - 1}{\Lambda^{3/2k} - 1} \quad \text{.....(24II)}$$

THE CALCULATION OF SCHEDULES

The method of calculating schedules referred to on page 167 is as follows.

By means of the technological bounds as stated on page 165, we can specify the ranges of values of θ and $1/\gamma$ which may be used. Suppose these are

$$\frac{1}{\gamma'} \leqslant \frac{1}{\gamma} \leqslant \frac{1}{\gamma''} \quad \text{.....(25II)}$$

and $\theta' \leqslant \theta \leqslant \theta''$ .....(26II)

Equation (26II) implies

$$s' \leqslant s \leqslant s'' \quad \text{.....(27II)}$$

Using equation (25II) it follows that

$$\frac{\log \Lambda}{(1-s') \log \left(\frac{1}{\gamma''} \right)} \leqslant 2k \leqslant \frac{\log \Lambda}{(1-s'') \log \left(\frac{1}{\gamma'} \right)} \quad \text{.....(28II)}$$

We now find solutions of equations (2II) and (5II) as follows:

Take a value for k which satisfies equation (28II) and assumes values for $1/\gamma_i$ and θ_i (i = 1, ----, $2k-1$) which satisfy equations (25II) and (26II) respectively. On substituting these values equations (2II) and (5II) are reduced to a pair of equations in two unknowns which may be solved to give $1/\gamma_{2k}$ and θ_{2k}. If these values satisfy the relevant inequalities, then $1/\gamma_i$, θ_i (i = 1, ----, $2k$), and k form a valid schedule. The number of strokes taken by this schedule may be evaluated by means of equation (19II).

18137 different combination values of $1/\gamma$, θ, and k were considered, of which 226 gave viable schedules, of these the thirty which gave the smallest number of strokes were printed out.

A selection from the results is given in Table III.

The best DSP schedule for the same operation with the same technological bounds is $1/\gamma = 1{\cdot}468$, $\theta = 1$, $k = 2$ and takes 29·33 strokes.

An interesting feature of these results is that an interchange of a pair of values of $1/\gamma$ or of a pair of values of θ can make a considerable difference to the number of strokes (cf. schedules 1 and 2).

APPENDIX III

TIME TAKEN TO COMPLETE A SCHEDULE

The time for one stroke is taken to be:

$$J = Ah\,(1-\gamma) \qquad \text{(1III)}$$

In the $2n-1^{\text{th}}$ pass

$$h = h_{2n-2} = \frac{h_0}{\lambda^{n-1}}$$

and so

$$J_{2n-1} = \frac{Ah_0\,(1-\gamma)}{\lambda^{n-1}} \qquad \text{(2III)}$$

In the $2n^{\text{th}}$ pass

$$h = w_{2n-1} = w_{2n-2}\,\gamma^{-s} = \frac{h_0\,\gamma^{-s}}{\lambda^{n-1}}$$

and so

$$J_{2n} = \frac{Ah_0\,(1-\gamma)\,\gamma^{-s}}{\lambda^{n-1}} \qquad \text{(3III)}$$

From Appendix II

$$m_{2n-1} = \frac{\ell_0}{h_0}\frac{\lambda^{3n-3}}{\theta} \qquad \text{(4III)}$$

$$m_{2n} = \frac{\ell_0}{h_0}\frac{\lambda^{3n-3}}{\theta}\lambda\gamma \qquad \text{(5III)}$$

Hence the total time for the n^{th} cycle is :

$$T_n = J_{2n-1}\,m_{2n-1} + J_{2n}m_{2n}$$

$$= \frac{Ah_0\,(1-\gamma)}{\lambda^{n-1}}\cdot\frac{\ell_0}{h_0}\frac{\lambda^{3n-3}}{\theta} + \frac{Ah_0\,(1-\gamma)}{\lambda^{n-1}}\gamma^{-s}\frac{\ell_0}{h_0}\frac{\lambda^{3n-3}}{\theta}\lambda\gamma$$

i.e. $$T_n = \frac{2\,A\,\ell_0\,(1-\gamma)\,\lambda^{2n-2}}{\theta} \qquad \text{(6III)}$$

Consequently the forging time for the whole schedule is:

$$T_F = \frac{2\,A\ell_0\,(1-\gamma)}{\theta}\sum_{n=1}^{k}\lambda^{2n-2}$$

$$= \frac{2\,A\ell_0}{\theta}\left(1-\Lambda^{\frac{1}{2k(s-1)}}\right)\left\{\frac{\Lambda-1}{\Lambda^{1/k}-1}\right\} \qquad \text{(7III)}$$

and the total time, including time for rotation and repositioning at the end of each pass is:

$$T = \frac{2\,A\ell_0}{\theta}\left(1-\Lambda^{\frac{1}{2k(s-1)}}\right)\left\{\frac{\Lambda-1}{\Lambda^{1/k}-1}\right\} + 2kS \qquad \text{(8III)}$$

PROOF OF EXISTENCE OF MINIMUM VALUE OF T

In what follows we assume $1/\gamma$ to be constant. In this case equation (8III) may be written as

$$T = \frac{B}{\theta\left(\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}-1\right)} + C\,(1+\theta) \qquad \text{(9III)}$$

where B and C are positive constants. This equation represents a sequence of discrete points corresponding to integral values of k. It is clear, however, that the values for integral k must lie on the curve which would result if k were allowed to vary in a continuous manner. We shall show that this curve has a minimum.

From equation (9III)

$$\frac{\mathrm{d}T}{\mathrm{d}\theta} = C - \frac{B}{\theta^2\left(\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}-1\right)^2}\left\{\left(\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}-1\right) - \theta\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}\log\left(\frac{1}{\gamma}\right)\frac{2}{1+\theta}\right\}$$

i.e.

$$\frac{\mathrm{d}T}{\mathrm{d}\theta} = C - B\left\{\frac{1}{\theta^2\left(\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}-1\right)} - \frac{2\left(\frac{1}{\gamma}\right)^{\frac{2}{1+\theta}}\log\frac{1}{\gamma}}{\theta\,(1+\theta)^2}\right\} \qquad \text{(10III)}$$

From equation (10III) it is evident that

$$\frac{\mathrm{d}T}{\mathrm{d}\theta} \to -\infty \text{ as } \theta \to 0$$

and $$\frac{\mathrm{d}T}{\mathrm{d}\theta} \to C \text{ as } \theta \to \infty$$

Now $\dfrac{\mathrm{d}T}{\mathrm{d}\theta}$ is continuous on $(0, \infty)$

and the range of $\dfrac{\mathrm{d}T}{\mathrm{d}\theta}$ covers $(-\infty, C)$.

Consequently there is at least one value of θ for which $\mathrm{d}T/\mathrm{d}\theta = 0$ and since $\mathrm{d}T/\mathrm{d}\theta$ is negative for small θ and positive for large θ, at least one of the values of θ which make $\mathrm{d}T/\mathrm{d}\theta$ zero must make T minimum.

EFFECT OF FORGING FROM ONE END OF BAR ONLY

If it is possible to forge from one end of the bar only then a further term must be added to T to allow for interpass manipulation times T_m. The precise form of the extra term depends on the relation between the manipulator acceleration f, its maximum velocity V, and the length of the bar.

The length during the first manipulator movement, i.e. at the end of the first pass, is $\ell_0\lambda$. The velocity which would be reached in this pass if the manipulator had acceleration f for half the distance and deceleration f for the other half is $\sqrt{(f\,\ell_0\lambda)}$. If $V < \sqrt{(f\,\ell_0\lambda)}$, then if t_n is the time for nth movement

$$t_n = \frac{\ell_n}{V} + \frac{V}{f} = \frac{\ell_0\lambda^n}{V} + \frac{V}{f} \qquad \text{(11III)}$$

and so

$$T_m = \frac{V}{f}(2k-1) + \frac{\ell_0}{V}\frac{\Lambda-\Lambda^{\frac{1}{2}k}}{\Lambda^{\frac{1}{2}k}-1} \qquad \text{(12III)}$$

During the last manipulator movement the length of the bar is $\ell_0\Lambda^{1-1/2k}$ of the manipulator had acceleration f for half this length and deceleration f for the other half, then the maximum velocity reached would be:

$$V_m = \sqrt{(f\,\ell_0\Lambda^{1-\frac{1}{2}k})} \qquad \text{(13III)}$$

This is the maximum usable manipulator velocity in this particular operation and increasing V beyond this limit results in no decrease in T_m.

If $V > V_m$, then

$$t_n = 2\left(\sqrt{\frac{l_0}{f}}\right)\lambda^{\frac{n}{2}} \quad \text{.....(14III)}$$

and

$$T_m = 2\left(\sqrt{\frac{l_0}{f}}\right)\left(\frac{\Lambda^{\frac{1}{2}}-\Lambda^{\frac{1}{2}k}}{\Lambda^{\frac{1}{2}k}-1}\right) \quad \text{.....(15III)}$$

If

$$\sqrt{(f\,l_0\Lambda^{\frac{1}{2}k})} < V < \sqrt{(f\,l_0\,\Lambda^{1-\frac{1}{2}k})}$$

then

$$\left(\sqrt{\frac{l_0\,\Lambda^{\frac{1}{2}k}}{f}}\right)\left\{(2k-1)+\frac{\Lambda-\Lambda^{\frac{1}{2}k}}{\Lambda^{\frac{1}{2}k}-1}\right\} < T_m < 2\left(\sqrt{\frac{l_0}{f}}\right)\left\{\frac{\Lambda^{\frac{1}{2}}-\Lambda^{\frac{1}{2}k}}{\Lambda^{\frac{1}{2}k}-1}\right\} \quad \text{.....(16III)}$$

In any case it is clear that for a constant Λ, T_m increases as k increases and that forging from one end only reduces the optimum value of θ for a given value of $1/\gamma$.

APPENDIX IV

AN EXAMPLE ON TAPERED SCHEDULES

For the purpose of this example we consider the operation of forging a bloom initially 4 ft long by 2 ft square to a forging ratio of $\Lambda = 9$. It is clear that the minimum time schedule for $\Lambda = 9$ takes a time not less than the time taken to perform two operations, one of $\Lambda = 3$ on a bar 4 ft long and the other, one of $\Lambda = 3$ on a bar 12 ft long (since in general, min $(A + B) \geq$ min A + min B, if A and B are both positive). From Fig.5 the least time schedule to produce $\Lambda = 3$ on a bar 4 ft long is $1/\gamma = 1{\cdot}3$, $\theta = 1{\cdot}4$, $k = 5$ and takes 2·05 min, the actual pressing time is $2{\cdot}05 - 10 \times 0{\cdot}05 = 1{\cdot}55$ min. If this schedule is continued for the second half of the operation, the pressing time in the second half is $3 \times 1{\cdot}55 = 4{\cdot}65$ min and the total time is $4{\cdot}65 + 10 \times 0{\cdot}05 = 5{\cdot}15$ min. Hence, the total time to produce $\Lambda = 9$ is 7·2 min.

For this operation $P = 1{\cdot}4 \times 1{\cdot}3 + \dfrac{1{\cdot}4 \times 1{\cdot}3^2}{2} = 2{\cdot}65$,

consequently the load necessary $L = 1526\ Y$, where Y is the yield stress of the material at the beginning of the operation. If $Y = 2{\cdot}9$ tons/in^2, then $L \approx 4430$ tons.

We now consider the following alternative method of producing a forging ratio of $\Lambda = 9$ on a bar initially 4 ft long and 2 ft square. We shall divide the operation into two parts, the first part as far as $\Lambda = 3$ and the second part from $\Lambda = 3$ to $\Lambda = 9$. The second part is to be performed according to the minimum time schedule for $\Lambda = 3$ whilst the first part is to be forged according to the fastest schedule which can be performed with a load not greater than that used in the second part.

As the second part is to be performed according to the minimum time schedule for $\Lambda = 3$, it will take 5·15 min. P for this part of the schedule is 2·65; consequently, the load for the second part of the schedule is $509\alpha Y$ where α is some factor to allow for the increase in yield stress during the first part of the forging. From experiments carried out in BISRA's laboratories, it seems that $\alpha = 2$ is reasonable. Taking this value of α the load in the second part of the schedule is $1018\ Y \approx 2950$ tons. If we use the same load in the first part, then $P = \dfrac{1018Y}{24 \times 24Y} = 1{\cdot}77$. Consequently $\theta/\gamma = 2\,(\sqrt{2{\cdot}77} - 1) = 1{\cdot}33$. If we maintain $1/\gamma$ at 1·3 the maximum θ which may be used is $\theta = 1{\cdot}02$. Referring again to Fig.5 we see that the fastest schedule for the first part of the operation is $1/\gamma = 1{\cdot}3$ $\theta = 0{\cdot}9$, $k = 4$ which takes 2·25 min. The total time for the whole operation is $2{\cdot}25 + 5{\cdot}15 = 7{\cdot}4$ min. The fastest DSP schedule for the whole operation if the maximum load is not to exceed 2950 tons is $1/\gamma = 1{\cdot}3$, $\theta = 0{\cdot}9$, $k = 4$, and the total time taken is 8·2 min.

Stal *in English*

Number 4 (April 1959) of the cover-to-cover translation of the Russian journal *Stal'* has been published, and subsequent issues should appear at about monthly intervals. Main contents of no.5 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

No.5

IRONMAKING

Blending iron ores
Firing of pellets
Hanging of the charge with oxygen-enriched blast
New design of seal for furnace charge distributor
Prospects for pig-iron production in electric furnaces

STEELMAKING

Use of sinter and briquettes instead of ore and limestone
Operation of open-hearth furnaces on natural gas
Moulds with wedge-shaped bottoms

ELECTROMETALLURGY

Rational design of secondary circuits for arc furnaces

FERROALLOYS

Thermal balance in the aluminothermic smelting of ferro-titanium

ROLLING AND TUBE PRODUCTION

Modern continuous billet mill
Effect of deformation speed during rolling
New developments in high-alloy tube production
A pusher-type rolling-mill charger
Tube parkerizing without sludge formation
Maximum angles of engagement during rolling

METAL SCIENCE AND HEAT TREATMENT

Influence of melting practice on the properties of Kh25N20 alloy
Effect of straightening on properties of P-65 high-carbon alloy rails

ECONOMICS AND ORGANIZATION

Experience in a production and labour organization office

HEAT TECHNOLOGY

Insulation of pipes in the hearths of continuous furnaces

SMALL COMPONENT PRODUCTION

Metal-ceramic and steel dies

POWER AND PLANT

Cooling of converter gases in waste-heat boilers

Correspondence on the paper

Behaviour of nitrogen in 3% silicon iron*

R. E. Fryxell, N. Galitzine, and F. S. Gardner

Dr **W. C. Leslie** and Mr **G. W. Momeyer** (E. C. Bain Laboratory for Fundamental Research, US Steel Corporation, Monroeville, Pa, USA) wrote: Since our knowledge of the silicon nitrides formed in silicon-killed and electrical steels, their solubility in ferrite and in austenite, the kinetics of their precipitation, and their chemical characteristics is in an unsatisfactory state, the authors' paper and their interest in these subjects are very welcome.

These comments are concerned with the chemical characteristics of the silicon nitrides and their solubility in ferrite. The conclusion by the authors that the nitrogen in 3%Si steel measured by the hydrochloric acid evolution method is in solid solution, and nitrogen not so measured exists in the form of precipitated silicon nitride is attractive, but it does not appear to be valid for steels in general. Some six years ago we tried to devise a means of separating AlN from Si_3N_4 when both might be present in steels. Assuming that Si_3N_4, as well as any AlN present, is quantitatively separated from the steel by Beeghly's bromine methyl acetate treatment, it seemed that silicon nitride might be determined in steels containing no aluminium by making a bromine methyl acetate separation and treating the residue with dilute HF. If aluminium were present in the steel, and if there is no solid solubility between the two nitrides, it was expected that a separation of AlN and Si_3N_4 in the extracted residue could be accomplished by treating the residue with dilute HCl or with dilute NaOH, either of which attacks AlN, then treating the remainder of the residue with dilute HF to determine Si_3N_4 nitrogen.

Composition of the steels used is in Table I; these values are all from check analyses. Since the quantity of silicon nitride or aluminium nitride depends on thermal history, the treatments given the steels before analysis are also given in Table I. The steels designated A and B were equilibrated by L. S. Darken in an NH_3–H_2 atmosphere at 600° C, i.e. they were held until the nitrogen content became constant. Substantially all of the silicon in these two steels is combined as Si_3N_4. Steel C was nitrided in a similar manner but was not equilibrated. The acid-soluble aluminium contents of these three steels are low, 0·004–0·006%. The other five samples were open-hearth steels containing 0·10 or 0·20%C. Specimens D1 and D2 were taken from a steel killed by addition of ferrosilicon in the furnace, which resulted in a silicon content of 0·18%. The acid-soluble aluminium content is low, 0·004%. Specimens E1, E2, and E3 were taken from a steel killed by an addition to the mould of 4 lb of Al per ton, which gave an acid-soluble aluminium content of 0·144%. The silicon content, 0·01% is low.

The nitrogen contents listed in Table I were the results of analyses for 'acid-soluble' nitrogen in the various steels. The samples were dissolved in 1 : 1 HCl, then treated with an excess of NaOH followed by distillation

* *JISI*, 1958, **189**, 327–332.

TABLE I Chemical composition, %, and heat-treatment of steels

Steel	C	Mn	P	S	Si	Al	Al_2O_3	N	Spectrographic Cr	V	Ti	Mo	Zr	B
A	0·064	0·26	0·052	0·023	0·20	0·004	...	0·168	...	...	...	...	...	...
B	0·074	0·28	0·012	0·015	1·21	0·005	...	0·84	...	...	...	...	...	...
C	0·073	0·28	0·020	0·022	0·58	0·006	...	0·0425	...	...	...	...	...	...
D1	0·20	0·83	0·011	0·018	0·18	0·004	0·001	0·0065	0·03	< 0·002	< 0·001	0·004	< 0·005	< 0·0005
D2	0·20	0·83	0·011	0·018	0·18	0·004	0·001	0·0060	0·03	< 0·002	< 0·001	0·004	< 0·005	< 0·0005
E1	0·10	0·44	0·012	0·023	0·01	0·144	0·015	0·0040	0·03	< 0·002	< 0·001	0·02	< 0·005	< 0·0005
E2	0·10	0·44	0·012	0·023	0·01	0·144	0·015	0·0035	0·03	< 0·002	< 0·001	0·02	< 0·005	< 0·0005
E3	0·10	0·44	0·012	0·023	0·01	0·144	0·015	0·0036	0·03	< 0·002	< 0·001	0·02	< 0·005	< 0·0050

Heat-treatments

A 352 h at 600° C in 3%NH_3–H_2, then 328 h in 1·13%NH_3–H_2 at 600° C, Q
B 252 h " " Q
C 48 h " " Q; 13½ h at 815° C in helium, FC
D1 Austenitized 1 230° C, held 5 min, quenched into lead at 595° C, held 24 h, AC
D2 Austenitized 870° C, held 5 min, quenched into lead at 595° C held 24 h, AC
E1 Austenitized 1 230° C, held 5 min, quenched into lead at 705° C, held 1 min, AC
E2 Austenitized 1 230° C, held 5 min, quenched into lead at 705° C, held 2 h, AC
E3 Austenitized 1 230° C, held 5 min, quenched into lead at 595° C held 1 h, AC

Note: Q = quenched FC = furnace cooled AC = air cooled

TABLE II Recovery of nitrogen from bromine methyl acetate residues of several steels

	Steels, wt-%N																							
	A				B				C				D1				D2				E1		E2		E3	
1 Acid-soluble N (determined from steels	0·168				0·84				0·0425				0·0065				0·0060				0·0040		0·0035		0·0036	
*Treatment of residues**																								
2 1 : 1 HCl, NaOH added, distilled	0·106	0·105			0·069	0·073			0·0056	0·0130			0·0053				...				0·0025		0·0033		0·0021	
	0·114				0·066				0·0056	0·0168			0·0053				...				0·0022		...		0·0024	
	...				...					0·0070			...				...				0·0023		...		...	
3 1 : 1 HCl + HF, NaOH added, distilled	...				0·84	0·85			0·0426	0·0380			0·0063				0·0041				...		...		...	
	...				0·84				0·0396	0·0365			0·0058				0·0041				...		...		...	
4 No acid treatment, distilled from 10 cm³ 1%NaOH	...				...				...				0·0040	0·0037			...				0·0021		0·0026		0·0020	
	...				...				...				0·0037	0·0041			...				...		0·0028		0·0020	
	...				...				...				0·0040				...				...		...		...	
5 Water washed, treated with HCl + HF, NaOH added, distilled	...				...				...				0·0062	0·0053			...				...		...		...	
	...				...				...				0·0055				...				...		...		...	
6 No acid treatment, distilled from 25cm³ 0·5%NaOH	...				...				...				0·0030				...				...		...		...	
7 No acid treatment, distilled from 10 cm³ water slightly alkaline	...				...				...				...				...				0·0015		...		...	
	...				...				...				...				...				0·0014		...		...	
8 No acid treatment, distilled from 10 cm³ 60%NaOH	0·089	0·076			0·041	0·021			0·0060	0·0065			...				0·0046				0·0023		...		...	
	0·104	0·090			0·047				0·0016	0·0036			...				0·0040				0·0020		...		...	
	...				...				0·0031	0·0024			...				...				0·0017		...		...	
	...				...				0·0056				...				...				...		...		...	
9 No acid treatment distilled from 25 cm³ 2%NaOH	...				...				...				0·0037				0·0039	0·0042			0·0015		0·0030		0·0019	
	...				...				...				...				0·0035	0·0038			...		0·0026		0·0021	
	...				...				...				...				0·0037				...		...		...	
10 2%HCl, distilled from 2% NaOH	...				...				...				0·0040				...				...		0·0032		...	
	...				...				...				...				...				...		0·0033		...	

* Residue from bromine methyl acetate separation

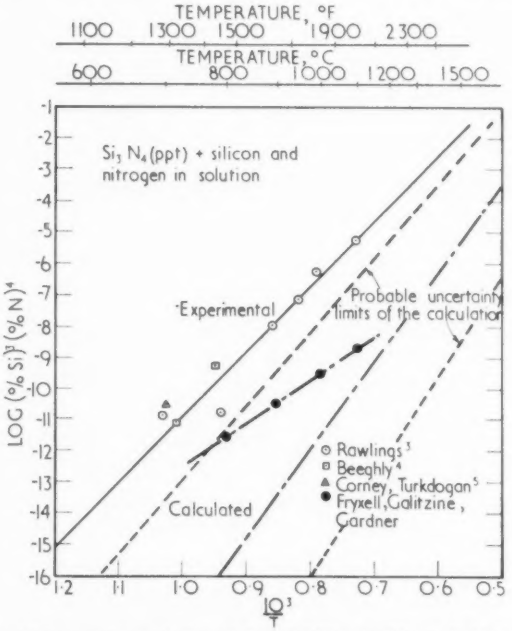
and collection of ammonia. Nessler's reagent was added to the distillate and the nitrogen content determined colorimetrically. For steels A, B, and C the analysis included use of HF. The treatments given steels A and B do not cause the formation of iron nitrides, therefore, with the exception of about 0·025%N kept in solid solution in ferrite by quenching from 600° C, the remainder of the nitrogen is present as Si_3N_4. Silicon nitride in these steels, at least after the heat-treatments employed, is acid soluble (HF being required for alloys containing over 0·5%Si).

The results of the various analyses performed on the bromine methyl acetate residues from the steels are given in Table II. For ease of comparison row 1 of the table again gives the results of the analyses for acid-soluble nitrogen made on the steels.

In row 2 are listed the results of analyses for 'AlN' nitrogen by the Beeghly method, i.e. solution of the sample in bromine methyl acetate, treatment of the residue with HCl and NaOH, followed by distillation. The results for steels A, B, and C containing only 0·004–0·006%Al are far in excess of the maximum amount of nitrogen that could be present as AlN. From this we concluded that silicon nitride is at least partially soluble in 1 : 1 HCl and hence that the presence of Si_3N_4 can interfere with the determination of AlN nitrogen in steels. This disagrees with the statement by Beeghly[1] that the method is not subject to interference from elements commonly present in carbon steels. Inspection of the analyses of steels used by Beeghly in his investigation of possible interference shows that all the steels containing more than residual amounts of silicon also contained comparatively large amounts of other nitride formers, i.e. Al, Cr, V, Mo, Ti, or Zr. Presence of these elements may have prevented formation of significant quantities of silicon nitride. This may explain his failure to observe interference from silicon nitride.

The quantity of AlN nitrogen determined in steels A, B, and C was considerably less than the total 'acid-soluble' nitrogen determined after solution of the steel in 1 : 1 HCl + HF, and data for steel C were quite erratic. These results may be the consequence of a particle size effect or of formation of silicic acid envelopes around silicon nitride particles.

When the residue from the bromine methyl acetate separation was treated with HCl + HF, recovery of nitrogen was complete (*see* row 3 of Table II). As a result of their thermal histories, the quantities of nitrogen recovered from the residues of steels B, C, and D1 were about equal to the total 'acid-soluble' nitrogen. The result for steel B is slightly high. In this instance, conversion of the intensity readings from the spectrophotometer were rather inaccurate since the method was not designed for use with such high concentrations of nitrogen. The acid-soluble nitrogen for steel B includes the



1 *Temperature variation of the solubility of silicon nitride in ferrite*

nitrogen held in solid solution in ferrite by quenching from 600° C, which amounts to about 0·025%. This nitrogen would be lost during the bromine methyl acetate separation, so the figure of 0·84%N for the residue from steel B must be high by at least 0·025%. The results shown in row 3 for steels B, C, and D1 lead to the conclusion that Si_3N_4 is separated quantitatively by the bromine methyl acetate treatment.

After the interference of Si_3N_4 in the Beeghly method had been determined, work proceeded on methods of separating AlN and Si_3N_4. To this end, residues from the bromine methyl acetate separation were distilled from 1% NaOH solution (row 4, Table II). The AlN nitrogen determined for the aluminium-killed steels E1, E2, and E3 were practically unchanged from that obtained by the original Beeghly method (row 2). However, this modification also produced AlN nitrogen from the silicon-killed steel D1, indicating that Si_3N_4 in this steel is attacked by 1%NaOH. Washing the residue of this steel with water (row 5) had no effect on the quantity of Si_3N_4 found as compared to the same procedure without water washing (row 3). Apparently Si_3N_4 from this steel is not attacked by water.

Omitting the acid treatment and distilling the residue of steel D1 from 25 cm³ of 0·5%NaOH (row 6) still produced a value for combined nitrogen, indicating that the silicon nitride was attacked even by this dilute solution of NaOH.

Row 7 of Table II gives the results obtained when the residue of the aluminium-killed steel E1 was distilled from 10 cm³ of nitrogen-free slightly alkaline water. Aluminium nitride is partly decomposed by this treatment. The lack of complete decomposition of AlN by this treatment makes it doubtful that a mixture of AlN and Si_3N_4 could be separated by washing with water. Beeghly[1] shows that 15 washes with hot water decomposed only about half of the AlN residue from a typical sample.

Both nitrides were decomposed when treated with a strongly alkaline solution (row 8), with a 2%NaOH solution (row 9), and with 2%HCl followed by distillation from 2%NaOH (row 10).

These results, combined with those of Fryxell, Galitzine, and Gardner, lead to the following conclusions:

(1) Si_3N_4 as well as AlN is quantitatively isolated by bromine methyl acetate solution of the iron matrix.
(2) The resistance to chemical attack of Si_3N_4 in steels seems to depend upon the composition and thermal history of the steel. These factors may influence the composition, structure, and particle size of the precipitated nitride.
(3) The presence of Si_3N_4 can interfere with the determination of aluminium nitride nitrogen by the Beeghly technique.

Experience in this laboratory indicates that when the silicon content of a steel is below about 0·5% the acid-soluble nitrogen content can be determined with an HCl treatment. When the silicon content is above about 0·5% the use of HF is required.

The situation is confused, and is likely to remain so until we obtain more information on the two forms of silicon nitride as they exist in steels, the time/temperature relationships for their precipitation, and possible differences in composition as well as structure between the two.

Figure 1 shows a plot of the logarithm of the solubility product of Si_3N_4 in ferrite as a function of 1/T for both calculated and experimental values. The calculation was made on the basis of the free energy of formation of Si_3N_4 from data of Hincke and Brantley[2] and from values for the activity coefficient of silicon in ferrite, referred to pure solid silicon as the standard state, expressed by the equation:

$$\log f_{Si}^{Fe} = \frac{-4540}{T} - 0{\cdot}549$$

TABLE III Composition of laboratory heats

	Sample, %		
	2	3	4
Si	2·58	2·73	2·88
Al	0·015	0·016	0·016
Ti	0·0013	0·0025	0·0009
B	0·0010	0·0029	0·0007
V	0·0035	0·0008	0·0025
Total N	0·0042	0·0053	0·0055
Acid-soluble N	0·0045	0·0010	0·0061
Inclusions (X-ray diffraction)	AlN	—	AlN

* No identifiable pattern

determined by R. W. Gurry, formerly of this laboratory. The rather large uncertainties involved make this calculation of little value, and more reliance is placed on the experimental determinations. These are based primarily on the data of Rawlings,[3] with support from the work of Beeghly,[4] and Corney and Turkdogan.[5] Both Rawlings and Beeghly used techniques that avoided the need for accurate determinations of very small quantities of nitrogen, and as can be seen from the figure, their results are in excellent agreement. The line drawn through the experimentally determined points corresponds to the equation:

$$\log (\%\,Si)^3\,(\%N)^4 = \frac{-20\,800}{T} + 9{\cdot}9$$

The data of Fryxell, Galitzine, and Gardner give much lower values for the solubility product, and since their values depend upon the accurate determination of very small quantities of nitrogen, the prior determinations are preferred. The solubility product values will contain an element of uncertainty until a distinction can be made between the solubilities of the two forms of silicon nitride.

AUTHORS' REPLIES

The **authors** wrote: The data presented by Dr Leslie and Mr Momeyer are interesting, and should add considerably to an eventual understanding of nitrogen reactions in iron which contains nitride-forming additives. Although our experience has been exclusively with 3%Si iron, we would like to make the following observations.

(1) In our paper, we stated that '. . . aluminium must be present at a level somewhat greater than 0·01% in 3%Si iron to compete with silicon for the available nitrogen.' The data on which this statement was based are given in Table III. These were laboratory heats containing varying amounts of impurities as given. The samples taken for analysis were 0·012-in. sheet quenched from 800° C. In two cases out of three, aluminium nitride was identified in extracted inclusions, and in these the acid-soluble nitrogen was equal to the total. The slightly lower vacuum-fusion results are indicative of the difficulty in obtaining complete nitrogen recovery in the presence of aluminium. On the other hand, sample 3 exhibited low acid-soluble nitrogen, and aluminium nitride was not observed. It is not known whether the additional titanium or boron (or both) in this sample might prevent the formation of both Si_3N_4 and AlN. The X-ray diffraction pattern of inclusions failed to show any identifiable compounds.

(2) Leslie and Momeyer assert that since iron nitrides do not form at 600° C, any nitrogen not in solid solution exists as silicon nitride in their samples A and B. On the basis of data in Table III, aluminium nitride can exist at 800° C even when the Si/Al ratio is nearly 200. Thus

TABLE IV Recalculated solubility products of Si_3N_4 in 3·25%Si iron

Temperature, °C	Dissolved nitrogen, %	fSi	K	log K
800	0·0006	2·00	$3·56 \times 10^{-11}$	−10·45
900	0·0011	4·61	$4·94 \times 10^{-9}$	−8·31
1 000	0·0019	9·46	$3·79 \times 10^{-7}$	−6·42
1 100	0·0029	16·80	$1·15 \times 10^{-5}$	−4·94

the presence of this compound in their samples should be considered as a possibility, and would account for a small part of the acid-soluble nitrogen found in the extracted residues.

(3) The interpretation that 'acid-soluble nitrogen' is uniquely nitrogen in solid solution appears to be valid for silicon iron only if specimens are quenched from temperatures higher than 700° C. That Si_3N_4 formed as lower temperatures is vulnerable to acid hydrolysis it shown by the work of Turkdogan and Ignatowicz[6] and some incidental experiments reported in our paper. Samples A, B, and C discussed by Leslie and Momeyer come in this category. It would be interesting to have comparable data on these samples after quenching from, say, 800° C. Beeghly reports for 1·19%Si iron that three-quarters of the 0·016%N was rendered acid insoluble by heat-treatment at 917° C[4].

(4) We agree with Leslie and Momeyer and with Beeghly[4] that nitrogen in silicon iron is completely acid soluble, independent of thermal history, up to a silicon level of about 0·5%. At the 3%Si level on the other hand we have without exception observed acid-soluble nitrogen behaviour in accord with Fig. 1 in our paper (using HCl and NaF in the solvent). At the intermediate silicon levels there appear to be some inconsistent data and differing opinions. Possibly in this region there is a transition between two or more forms of silicon nitride, or between predominantly smaller and predominantly larger particles. X-ray diffraction studies of extracted residues in this range of silicon contents would be desirable.

Concerning the figure presented by Leslie and Momeyer, we wish to make the following comments.

(1) Their data demonstrating the acid solubility of silicon nitride under certain conditions may be taken as an implied criticism of our hypothesis that acid-soluble nitrogen is uniquely that in solid solution. If this criticism is valid, the solubility data we present for nitrogen in equilibrium with precipitated silicon nitride are high, since these values include some contribution from an unknown amount of nitride which hydrolyzed during analysis. Thus, corrections would shift our data in the direction of the *calculated* curve in the figure, and heighten the disagreement with the other experimental data.

(2) Our acid-soluble nitrogen data were not corrected for a small reagent blank, which was usually 0·0003% or less. If this correction were applied, it too would shift our data in the direction of the calculated curve.

(3) On the other hand, the large discrepancy between our data and the others shown in the figure is not surprising if it is recognized that all of the solubility products are calculated in terms of weight-percent. With the exception of the single result at 2·83%Si taken from the work of Corney and Turkdogan, all of the data compared with ours were obtained with alloys containing 1·9%Si and less. In our work, only 3·25%Si alloys were used. For this composition, the departure from ideality of the solute silicon is considerably greater than in the region less than 2%. This is shown graphically in Fig. 4 of a recent paper by Seybolt.[7] In this figure, an experimental quantity proportional to silicon activity is plotted against weight-percent silicon at 800° C. Two curves are given for alloys containing more than about 1·3%Si. These correspond to metastable (disordered) and stable (ordered) lattices. For our specimens, which were all water quenched, the disordered state is expected.

From Seybolt's data we have estimated the activity coefficient for silicon in 3·25%Si iron as 2·00 at 800° C, letting $f = a/\%\text{Si}$. This value can be used to recalculate the solubility product for Si_3N_4 in terms of activities, defined as follows:

$$K = [a_{Si}]^3 [a_N]^4 = (\%\ \text{Si} \times f)^3\ (\%\ N_{\text{sol. soln.}})^4$$

(neglecting any small non-ideality of dissolved nitrogen). Further, from the expression cited by Leslie and Momeyer, activity coefficients for silicon may be calculated for other temperatures. Combining these with Seybolt's data for 800° C, a set of recalculated solubility products is given in Table IV. It is apparent that these agree much better with the other experimental values determined for lower silicon contents. The latter should of course also be corrected with activity coefficients, but this correction is relatively small. For example, Rawling's value for log K at 800° C becomes about −10·3. The recalculated data in Table IV correspond to a heat of solution for Si_3N_4 in ferrite of about 120 kcal/mole. To the extent that the activity corrections are valid, the heat of solution of 60 kcal/mole given in our paper is incorrect. Nevertheless, the solubility products previously given are considered valid for 3·25%Si iron if it is kept in mind that they are calculated in terms of weight-percent.

(4) Further support for the recalculated value of the heat of solution of Si_3N_4 in ferrite is as follows, as pointed out to us by Dr A. U. Seybolt.

For the reaction

$$2N_2 + 3\,Si = Si_3N_4$$

Hincke and Brantley give a heat of formation of −176·3 kcal.[2]

For the reaction

$$3\,Si = 3\,Si\ (\text{in iron})$$

Seybolt gives a heat of solution of −87·3 kcal, as determined for 3·3% (metastable) silicon iron.[7]

From these,

$$\Delta H = -89\ \text{kcal for the reaction}$$
$$2N_2 + 3\,Si\ (\text{in iron}) = Si_3N_4$$

Combining with

$$\Delta H = -31\ \text{kcal for the reaction}$$
$$4N\ (\text{in iron}) = 2\ N_2$$

the heat of solution is derived as −120 kcal for the reaction

$$3\,Si\ (\text{in iron}) + 4\,N\ (\text{in iron}) = Si_3N_4$$

The excellent agreement between the calculated and observed heats of solution of Si_3N_4 in ferrite lends considerable support to both the temperature coefficient of activity determined by Gurry, and the interpretation of acid-soluble nitrogen proposed in our paper.

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NEWS | *Announcements and News of Science and Industry*

THE IRON AND STEEL INSTITUTE

Autumn General Meeting

The Autumn General Meeting of the Institute will be held in London from Wednesday to Friday, **2 to 4 December.** The main technical sessions will be devoted to the presentation and discussion of a series of papers on hot and cold deformation, including forging and extrusion. There will also be sessions devoted to the evolution and prevention of fumes in steelmaking processes and to metallurgical subjects. Full details will be published in the November issue of the *Journal*.

Twelfth Hatfield Memorial Lecture

The Twelfth Hatfield Memorial Lecture will be delivered at Sheffield on the evening of Wednesday, **25 November,** by Academician G. Kurdjumov, of the Department of Physical Metallurgy, Central Research Institute for Ferrous Metallurgy, Moscow. The subject of the lecture will be *The phenomena occurring in steels during quenching and tempering.*

Joint meeting on corrosion

A joint meeting of The Iron and Steel Institute and the Corrosion Group of the Society of Chemical Industry is being held on Thursday, **15 October,** at 2 pm to discuss the Sixth Report of the Corrosion Committee, which was published recently as No.66 in the Institute's Special Report Series. Joint Chairmen of the meeting will be Dr U. R. Evans, F.R.S., and Mr L. Kenworthy.

Admission to the meeting, which will take place at the rooms of the Society of Chemical Industry, 14 Belgrave Square, London SW1, will be by ticket only; tickets may be obtained on application to the Secretary of The Iron and Steel Institute.

Symposium on determination of gases in metals

The Society for Analytical Chemistry, The Iron and Steel Institute, and The Institute of Metals are holding a joint symposium on Tuesday and Wednesday, **3 and 4 May 1960,** at Church House, Great Smith Street, London SW1, on 'The determination of gases in metals'. Three sessions are envisaged, occupying the afternoon of the Tuesday and the morning and afternoon of the Wednesday. At the first session, invited review papers will be presented, covering the determination of oxygen, hydrogen, and nitrogen respectively in a general way; the other two sessions will be devoted to shorter papers and discussions dealing with specialized aspects of the field.

It is intended that preprints of all the papers shall be available before the start of the symposium, and that the proceedings, including discussions, shall be published in a single volume at a later date.

Sidney Gilchrist Thomas Memorial

The first list of contributions to the Sidney Gilchrist Thomas memorial fund (see *JISI*, August 1959, pp.384-385) is as follows:

Richard Thomas and Baldwins Ltd	1000	0	0
The Whitehead Iron and Steel Co. Ltd	1000	0	0
Guest Keen and Nettlefolds Ltd	500	0	0
The Steel Company of Wales Ltd	500	0	0
The Park Gate Iron and Steel Co. Ltd	50	0	0
Round Oak Steel Works Ltd	50	0	0
Skinningrove Iron Co. Ltd	25	0	0
Edgar Allen and Co. Ltd	10	10	0
Thos. Firth and John Brown Ltd	5	5	0
The Darlington Forge Ltd	2	2	0
The North British Steel Foundry Ltd	2	2	0
Total	£3144	19	0

INCREASED PRICES FOR THE JOURNAL TO NON-MEMBERS Owing to the continuing increase in the cost of printing, it has become necessary to raise the prices for the sale of the *Journal* of The Iron and Steel Institute *to non-members* from 1 January 1960. Members and Associate Members of the Institute will continue to be supplied with one copy of the monthly *Journal* free; the price to them for extra copies and bound volumes will remain unchanged.

The revised prices are:

	Published price	*Members*	*Public libraries and technical societies*
Monthly Journal (1960 onwards)			
Subscription rate p.a.	£12 0*s.* 0*d.*	£6 0*s.* 0*d.*	£10 0*s.* 0*d.*
packing and postage	12*s.* 0*d.*	12*s.* 0*d.*	12*s.* 0*d.*
Single issues	£1 5*s* 0*d.*	15*s.* 0*d.**	£1 0*s.* 10*d.*
packing and postage	1*s.* 0*d.*	1*s.* 0*d.*	1*s.* 0*d.*
Bound volumes (1960 onwards)			
Subscription rate p.a. (3 vols)	£12 0*s.* 0*d.*	£6 0*s.* 0*d.*	£10 0*s.* 0*d.*
packing and postage	6*s.* 0*d.*	6*s.* 0*d*	6*s.* 0*d.*
Single volumes	£5 0*s.* 0*d.*	£2 0*s.* 0*d.*	£4 3*s.* 4*d.*
Packing and postage	2*s.* 0*d.*	2*s.* 0*d.*	2*s.* 0*d.*

* Members and Associate Members wholly engaged in academic, teaching, or scientific work who require single copies for their own personal use will be given a special rate on application.

NEWS OF MEMBERS

Mr **W. J. Allday** is spending a year on research at the University of British Columbia, Vancouver, Canada.

Mr **T. R. Allmand** has left BISRA to join the senior staff of the central research department, Dorman, Long (Steel) Ltd.

Mr **A. C. Bird** has been appointed works manager of Davy and United Roll Foundry Ltd.

Mr **A. M. Horsfield** has left the British Welding Research Association to join ESAB Ltd.

Mr **L. A. Leonard** has left BISRA to join the central research laboratories of Richard Thomas and Baldwins Ltd.

Dr **B. R. Nijhawan** has been elected president of the Institute of Indian Foundrymen.

Mr **L. R. P. Pugh**, director and secretary of Guest Keen Iron and Steel Co. Ltd, has been appointed assistant managing director.

Professor **E. Rudberg** has been appointed secretary of the Swedish Royal Academy of Science, and has therefore resigned the directorship of the Institute for Metal Research in Stockholm.

Mr **M. N Saxena** has been awarded the master's degree in metallurgical engineering by the University of Wisconsin. He has now returned to resume his duties as reader in metallurgical engineering at the University of Roorkee, India.

Mr **R. B. Sharp** has been appointed managing director of Barrow Ironworks Ltd.

Obituary

Mr **William James Chalmers** (*elected* 1943), of Birmingham, on 10 August 1959.

IRON AND STEEL ENGINEERS GROUP

Meeting of junior engineers in Glasgow

A meeting of junior engineers is being held in Glasgow on Wednesday and Thursday, **28 and 29 October.** There will be a technical session on the Wednesday morning, and in the afternoon a visit to the Ravenscraig works of Colvilles Ltd. On the Thursday, there will be alternative all-day visits to the General Terminus Quay, Clyde Iron Works, and Clydebridge Works of Colvilles Ltd, or to the Clydesdale Steel and Tube Works of Stewarts and Lloyds Ltd and to the works of the North British Locomotive Co. Ltd.

POWDER METALLURGY JOINT GROUP

Forthcoming meetings

A symposium on 'The powder metallurgy of magnetic materials' is to be held at Church House, Great Smith Street, London SW1, on Wednesday, **16 December.** It will be based on a series of invited papers describing original work, all of which are to be published in *Powder Metallurgy*, Part 4, which will be available before the meeting.

The Spring Meeting of the Joint Group will be held at Church House on Monday and Tuesday, **11 and 12 April 1960.** The subject of the meeting will be 'Continuous processing in powder metallurgy'.

CONTRIBUTORS TO THE JOURNAL

G Acevedo Design engineer, Bell Telephone Laboratories, New York.

Generoso Acevedo was born in Puerto Rico in 1934; he moved to New York in 1939 and was educated in the New York Public Schools. After graduating from the Bronx High School of Science, he began studies as an evening student at the Cooper Union for the Advancement of Science and Art while employed as a research assistant in the Heat and Mass Flow Analyzer Laboratory of Columbia University. He entered the US Army in 1957, and after two years' service took up his present position in the trial installations department of the Bell Telephone Laboratories.

J. Banbury, A.M.I.E.E. Director. ORbit (Operational Research) Ltd.

John Banbury was apprenticed in the electronics industry and took the Higher National Certificate in Electrical Engineering in 1942. He joined the Royal Navy in 1943, and was demobilized in 1946 with the rank of Engineer Lieutenant. He then went to Faraday House Electrical Engineering College to finish his course in electrical engineering.

After short spells in illuminating engineering and technical editing he joined the National Coal Board's operational research group in 1952. During his time with the Board he worked chiefly on pit trials of non-inflammable conveyor belting, and after eighteen months

G. Acevedo

J. Banbury

C. F. Bonilla

J. V. Chelsom

he was appointed head of the section responsible for this work. In 1955 he joined the Operational Research Department of BISRA, and was directly responsible for the early work of the department on forging. He was deputy head of the department when he left earlier this year to become a director of ORbit (Operational Research) Ltd, where he is now the partner in charge of projects.

C. F. Bonilla, A.B., B.S.(E.E.), CH.E., PH.D. Professor of Chemical Engineering, Columbia University, New York.
Charles F. Bonilla was born in the USA in 1909 and educated at the Institute level in Spain and later at Columbia University, where he obtained his doctorate in 1933. He taught chemical engineering until 1937 at the College of the City of New York, and then until 1949 at the Johns Hopkins University, becoming head of the department in 1943. Dr Bonilla has been Professor of Chemical Engineering at Columbia since 1948. He has specialized in heat transfer, especially in nuclear reactors; during the period 1957–1959 he has been on leave from Columbia as director of the Puerto Rico Nuclear Centre (Atomic Energy Commission).

J. V. Chelsom, B.SC.(ECON.), F.S.S. Ford Motor Company Ltd.
Mr Chelsom, who is 26, was born at Weymouth and educated at Weymouth Grammar School and the London School of Economics, where he specialized in statistics and obtained the B.Sc. (Econ.) Hons. degree. He joined the Operational Research Department of BISRA after completing his National Service.

R. H. Collcutt, B.SC.(ENG.) Head of Operational Research Department, British Iron and Steel Research Association.
Roger Hugh Collcutt was educated at the Cathedral School, Truro, and at University College, London. From 1943 to 1945 he was with the operational research section of HQ Bomber Command. He joined the Scientific Adviser's Department of the Air Ministry in 1946, where he remained until he was appointed to his present position with BISRA in 1955.

S. G. Glover, B.SC., PH.D. Lecturer, Department of Physical Metallurgy, Birmingham University.
Stanley George Glover was born in Birmingham in 1925 and educated at Solihull School, Warwickshire. After two years in industry, he served in the Royal Navy from 1943 to 1946, and then entered Birmingham University in 1947. On graduating in physical metallurgy in 1951 he became a research assistant in the Department of Physical Metallurgy; he was appointed to his present post in 1953. He was awarded the degree of Ph.D. in 1957 for work on the martensitic transformation in steels.

R. H. Collcutt

S. G. Glover

C. Holden

H. W. King

C. Holden, B.SC., A.M.INST.P. Head of furnace research section, research and development department, The United Steel Companies Ltd.
Charles Holden was educated at Rotherham Grammar School; on leaving school he joined William Jessop and Sons Ltd, working in their magnetic research department from 1943 to 1945. After two years in the army, with the Royal Corps of Signals, he spent 2½ years at Rotherham Technical College, studying for an external degree of London University. Mr Holden then joined the BSA Group Research Centre, spending nine months with that organization as an X-ray metallographer.
He joined the research and development department of The United Steel Companies Ltd at the beginning of 1951; since then he has been working in the furnace research section, for the last three years as section head, on heat transfer, combustion, and fume emission problems. He was awarded the Williams Prize by The Iron and Steel Institute in 1958 for a paper on the protection of refractories by moving air curtains.

H. W. King, B.SC., PH.D. Fellow, Mellon Institute, Pittsburgh, USA.
Hubert Wylam King was born at Cardiff in 1930; his family travelled to India in 1932, and he received his secondary education at the Lawrence Memorial Royal Military School, Nilgiri Hills, Madras Province. On returning to England he worked with Rubery, Owen and Co. Ltd from 1947 to 1949 as apprentice metallurgist and studied at the County Technical College, Wednesbury, obtaining his Ordinary National Diploma in Metallurgy. He was awarded a Technical State Scholarship and proceeded to the Department of Physical Metallurgy, University of Birmingham, receiving his B.Sc. degree in 1954, and his Ph.D. degree in 1956. After two years as research fellow in physical metallurgy, during which he extended his studies of the first stage of tempering, he was appointed to his present position, and is now engaged in research on the accurate measurement of lattice spacings in close-packed hexagonal alloys.

V. Paschkis

A. Shutt

G. Stolz, jun.

O. C. Wells

V. Paschkis, SC.D. Associate Professor, Department of Mechanical Engineering, and Director of the Heat and Mass Flow Analyzer Laboratory, Columbia University, New York.
Victor Paschkis was born and educated in Vienna; he obtained the degrees of M.E., E.E., and SC.D. from the Institute of Technology, Vienna, between 1921 and 1923. From 1922 to 1930 he worked for various industrial companies in Europe, and from 1930 to 1938 he was a consulting engineer.
Dr Paschkis emigrated to the USA in 1938, and worked in the field of industrial electric furnaces, first with the A. F. Holden Company (1938 – 1939) and later with the Ajax Electric Company (1939–1940). In 1940 he suggested to Columbia University that an analogue computer might be built to specialize in problems of heat transfer. He designed and supervised the erection of the Heat and Mass Flow Analyzer Laboratory, and became its director on its completion.

A. Shutt, B.SC. Mechanical Working Division, British Iron and Steel Research Association.
Mr Shutt was born in 1928 and educated at Firth Park Grammar School, Sheffield. On leaving school he spent some years working in a rolling mill. In 1952 he attended part-time classes at Rotherham Technical College, and entered Sheffield University in 1953 to read mathematics. After graduating in 1956, he spent some time doing research on linear operator theory, and joined BISRA in 1958.

G. Stolz, jun., B.E., M.S. Senior Research engineer, Heat and Mass Flow Analyzer Laboratory, Columbia University, New York.
George Stolz was born in 1929 and educated at the Williston Academy, Easthampton, Mass., and at Yale University, where he obtained the B.E. degree in chemical engineering in 1951. He has been working on the thermal fundamentals of the quenching at Columbia University since 1953. He was awarded the M.S. degree in 1957, and is at present a candidate for the D.ENG.SC. degree in chemical engineering.

O. C. Wells, M.A., PH.D. Research physicist, Westinghouse Research Laboratories, Pittsburgh, Pa.
Oliver Wells was born in London in 1931 and educated at Marlborough College and at Trinity College, Cambridge, where he obtained the degrees of M.A. in mathematics and PH.D. in electrical engineering. He joined Ericsson Telephones Ltd in 1957, and took up his present position in July of this year.

G. W. Wilson, B.SC., PH.D., A.INST.P.—Senior metallurgist in charge of physical metallurgy section, Hawker-Siddeley Nuclear Power Co. Ltd.

Dr Wilson was born in 1929 at Grimsby and educated at the Humberstone Foundation Grammar School. He was awarded an external B.SC.(HONS.) degree in physicsby London University in 1949, and a PH.D. by Nottingham University in 1952 for work on the magnetic properties of single crystals of nickel and nickel–iron alloys. In that year he joined the Royal Naval Scientific Service and worked on underwater weapons and on devices for measuring the magnetic field of ships. He was appointed to his present position on the creation of the company in 1956.

FORTHCOMING CONFERENCES AND EXHIBITIONS

Heating and ventilation

A conference on heating and ventilation is being held on Thursday, 5 November, at the Institution of Mechanical Engineers, Birdcage Walk, London SW1. Organized by the British Occupational Hygiene Society, the conference will be devoted to a discussion of the problems of heating and ventilation as they affect personnel working in arduous environments. Full details may be obtained from Dr D. Turner, Associated Ethyl Co. Ltd, Ellesmere Port, Cheshire.

Building exhibition

The 1959 Building Exhibition will be held at Olympia, London, from 18 November to 2 December.

Pilot plants in research

A symposium on pilot plants in metallurgical research and development is being held under the auspices of the National Metallurgical Laboratory, Jamshedpur, India, early in February 1960.

The subjects covered will include pilot-plant projects in relation to laboratory-scale investigations, mineral dressing, electrometallurgical plants, refractories, hot and cold working, and finishing processes.

Electrometallurgy

The Electrometallurgical Centre of the Associazione Italiana di Metallurgia is holding a symposium on electrolysis of molten salts and the production of special metals by electrothermal methods in the Spring of 1960. The symposium will take place in Milan, and a series of visits to works and laboratories has been arranged in conjunction with it. Those interested should apply to the AIM at Via Moscova 16, Milan.

Factory equipment

The next Factory Equipment Exhibition will be held in Manchester, opening on 21 September 1960. In the following year it is to be held in London again, at Earl's Court. It is proposed to alternate between London and the north of England in the future.

Metallic corrosion

The first International Congress of Metallic Corrosion is to be held in South Kensington, London, from 10 to 15 April 1961, under the presidency of Sir Harry Melville, K.C.B., F.R.S. Mr E. Leslie Streatfield has been appointed chairman of the executive committee and Dr J. Ferguson chairman of the finance committee. The honorary secretary is Lt-Col F. J. Griffin, from whom further information may be obtained at 14 Belgrave Square, London SW1.

Impact of nuclear development

The measurement and control section and the supply section of The Institution of Mechanical Engineers are organizing jointly a convention on the impact of nuclear development on electricity supply and on instrument techniques, to be held in London in September 1961.

Among the subjects to be discussed will be present and future energy requirements, economics, operating characteristics, the siting of nuclear power stations, health physics, nuclear measuring instruments for research and process control, and data processing. The organizing committee will be pleased to receive offers of papers for inclusion in the convention.

NEWS OF SCIENCE AND INDUSTRY

Continuous casting at Distington

Distington Engineering Co. Ltd, a subsidiary of The United Steel Companies Ltd, have established a continuous casting division, which will specialize in the design and manufacture of continuous casting plants for both ferrous and non-ferrous metals. The company will design and build plants on behalf of and under licence from Concast AG of Zurich, in which United Steel recently became shareholders.

The personnel of the new division have been closely associated with the experimental machines that have been developed and operated by United Steel since 1952. This experimental work will continue; the current programme includes the production of slabs 36 in. wide × 5 in. thick and 9 in. square billets. Killed, rimming, and stainless steels have been cast successfully in these sizes.

Ravenscraig contracts

The order for the building of the 68 in. semi-continuous hot strip mill for the Ravenscraig works of Colvilles Ltd has been placed with Davy and United Engineering Co. Ltd, Sheffield.

The new mill will comprise a 42 in. vertical edging scale-breaker, a 44 × 68 in. horizontal scale-breaker, a 39 and 56 × 68 in. reversing roughing mill with attached 33 in. vertical edger, a rotary crop shear, a 28 and 56 × 68 in. six-stand finishing mill, two downcoilers and coil unloaders, and ancillary equipment. It will have an initial output of 500000 tons of strip products per year; however, the mill is designed for an eventual output exceeding 1500000 tons annually. The mill will produce strip and light plate from 24 to 60 in. wide, in coils weighing up to 40000 lb.

The coke-oven and by-product plants at Ravenscraig are to be built by Woodall-Duckham Construction Co. Ltd; this will be the fourth complete installation of this kind built by Woodall-Duckham for Colvilles.

Ashmore, Benson, Pease and Co., a member of the Power-Gas Group, have received an order for a second blast-furnace plant at Ravenscraig. The furnace will have a hearth diameter of 25 ft 9 in. and will be designed to produce over 1000 tons of basic iron per day. This plant will be similar to the No.1 blast-furnace which the same firm completed for Colvilles in 1957.

INDUSTRIAL PUBLICATIONS RECEIVED

The Tyne Wire Rope Manufacturing Co. Ltd has produced a handsome 118-page catalogue of mining and engineering steel wire ropes.

'How to use Araldite Epoxy Resin Adhesives' is the title of a very informative booklet from Ciba (A.R.L.) Ltd.

From the Incandescent Heat Co. Ltd come leaflets on cupolas (F.P.1.) and dust arresters (F.P.2) for foundry plant.

Two brochures from Head, Wrightson and Co. Ltd cover the activities of the companies in the group, and the services offered to the iron and steel industry respectively. Both are in French, German, and Spanish as well as English.

Dixylon plastic transmission belting is the subject of a brochure from R. and J. Dick Ltd.

Crofts (Engineers) Ltd have recently published leaflets on free space hydraulic couplings and drives (1-5814) and 'Ritespeed' geared motors (5950).

Gibbons Brothers Ltd have produced a booklet describing some of their activities working in collaboration with OFU Ofenbau-Union GmbH of Düsseldorf.

The H 800 recording infra-red spectrophotometer is described in a leaflet from Hilger and Watts Ltd.

CHANGES OF ADDRESS

The Bristol branch office of the English Electric Co. Ltd is now Equity and Law Buildings, 36-38 Baldwin Street, Bristol 1 (telephone 27304).

The head office and Ontario regional office of the Canadian Institute of Steel Construction Inc. has moved to 388 Yonge Street, Toronto 1, Ontario, Canada.

The new address of the Newcastle Office of the Lancashire Dynamo Group is Eagle Star House, 32–34 Mosley Street, Newcastle-upon-Tyne 1 (telephone 28621 and 29736).

The headquarters of the Metal Powder Industries Federation has moved to 60 East 42nd Street, New York 17, NY.

The Scottish area office of Evershed and Vignoles Ltd is now at 30 Rutland Square, Edinburgh 1 (telephone Fountainbridge 3056).

Davy British Oxygen Ltd is now at Darnall Works, Sheffield (telephone 49971).

DIARY

4–10 Oct. INSTITUTO DEL HIERRO Y DEL ACERO—4th General Meeting—Madrid.

4–10 Oct. 26th INTERNATIONAL FOUNDRY CONGRESS—Madrid.

5–7 Oct. ASSOCIATION OF SPECIAL LIBRARIES AND INFORMATION BUREAUX (ASLIB)—34th Annual Conference—Scarborough.

7 Oct. BRITISH NUCLEAR ENERGY CONFERENCE—*The prospect for a nuclear-powered dry-cargo liner*, by E. C. B. Corlett and E. P. Hawthorne—Institution of Naval Architects, 10 Upper Belgrave Street, London SW1, 4.45 pm.

14 Oct. MANCHESTER METALLURGICAL SOCIETY—Presidential addresses, by Dr E. F. Emley—Central Library, Manchester, 6.30 pm.

15 Oct. THE IRON AND STEEL INSTITUTE and SOCIETY OF CHEMICAL INDUSTRY (CORROSION GROUP)—Joint meeting on corrosion—14 Belgrave Square, London SW1, 2 pm.

15 Oct. LIVERPOOL METALLURGICAL SOCIETY—Presidential address: *The production and use of steel wire and steel wire ropes*, by B. Ryan—Department of Metallurgy, Liverpool University, 7 pm.

19–24 Oct. SOCIÉTÉ FRANÇAISE DE MÉTALLURGIE–Journées Métallurgiques d'Automne—Maison de la Chimie, Paris.

21 Oct. LIVERPOOL METALLURGICAL SOCIETY—Visit to Rylands Brothers Ltd., Warrington.

22–23 Oct. BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Open Days—140 Battersea Park Road, London SW11.

23 Oct. WEST OF SCOTLAND IRON AND STEEL INSTITUTE — Presidential address, by J. W. Todd—39 Elmbank Crescent, Glasgow, 6.45 pm.

28 Oct. MANCHESTER METALLURGICAL SOCIETY—*Metallurgical research in the USSR*, by Dr K. J. Irvine—Central Library, Manchester, 6.30 pm.

28–29 Oct. THE IRON AND STEEL ENGINEERS GROUP (Iron and Steel Engineers Group)—Meeting of Junior Engineers, Glasgow.

1–6 Nov. AMERICAN SOCIETY FOR METALS—41st National Metallurgical Congress and Exposition—Chicago, Ill., USA.

4 Nov. BRITISH NUCLEAR ENERGY CONFERENCE—*The design and testing of large gas ducts*, by A. T. Bowden and J. C. Drumm—Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1, 6 pm.

4–6 Nov. VEREIN DEUTSCHER EISENHÜTTENLEUTE—Eisenhüttentag—Düsseldorf.

5 Nov. LIVERPOOL METALLURGICAL SOCCIETY—*Ductile fracture*, by Professor R. W. K. Honeycombe—Department of Metallurgy, Liverpool University, 7 pm.

11 Nov. LIVERPOOL METALLURGICAL SOCCIETY—*Welding in warship construction*, by W. R. Seward—Picton Library, Liverpool, 7.30 pm

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 74 of the September 1959 issue of the *Journal*:

New Methods of Plastic Deformation in the Working of Metals
PLATZER, F., *Berg- u. Hüttenmänn. Monatsh.*, 1957, Apr., pp.115–125. (£6) [**918**

Torsion-resistant Box Girders in Steelworks Crane Construction.
SCHWARZ, H., *Stahl u. Eisen*, 1957, Jan. 10, pp.24–32. (£3 15*s*. 0*d*.) [**923**

Aerodynamic Design of the Open-hearth Furnace. III–Functions of the Lower Furnace.
HASIMOTO, H. A., *Tetsu-to-Hagane*, 1957, Feb., pp.117–121. (£8) [**1122**

Aerodynamic Design of the Open-hearth Furnace., IV–Function of the Furnace Chamber.
HASIMOTO, H. A., *Tetsu-to-Hagane*, 1957, June, pp.628–632. (£7 10*s*. 0*d*.) [**1123**

An Explanation of Interference Errors Occurring Systematically in X-ray fluorescence-spectroscopic Measurements and Means whereby these Interference Errors may be eliminated.
EBERT, F., and WAGNER, A., *Z. Metallk.*, 1957, Dec., pp.646–649. (£2 15*s*. 0*d*.) [**1177**

Counter-tube Technique with a Newly-developed Specimen Holder for the Representation of Textures in Quantitative Pole-figures.
GREWEN, J., *et al.*, *Arch. Eisenhütt.*, 1958, Feb., pp.115–118. (£3 5*s*. 0*d*.) [**1196**

Experience with Multiple-strand Semi-continuous Casting.
BAAKE, R., and ROSAHL, H., *Neue Hütte*, 1958, Dec., pp.740–746. (£3 10*s*. 0.) [**1224**

Growth and Morphology of Oxide Films on Iron at High Temperatures (with Discussion).
MOREAU, J., and CAGNET, M., *Rev. Mét.*, 1958, Nov., pp.1091–1109. (£7 10*s*. 0*d*.) [**1225**

The Desulphurization and Deoxidation of Pure Iron in the Vacuum Melting Process.
JÄNICHE, W., and BECK, H., *Arch. Eisenhütt.*, 1958, Oct., pp.631–642. (£5 15*s*. 0*d*.) [**1227**

Jet Tapping of Open-hearth Furnaces. (Abridged.)
PRIOR, J., I–Method of Construction and Operation.
BURMEISTER, W., II–Experience gained, *Stahl u. Eisen*, 1957, May 2, pp.562–567. (£2 10*s*. 0*d*.) [**1234**

Effect of Arsenic, Copper, Tin and Molybdenum on Impact Properties of Dead Soft Steel.
SAWAMURA, H., *et al.*, *Tetsu-to-Hagane*, 1955, Jan., pp.23–31. (£10) [**1239**

Effect of Carbon, Arsenic, Copper and Tin on Transition Temperature of Steel.
SAWAMURA, H., *et al.*, *Tetsu-to-Hagane*, 1955, Aug., pp.861–869. (£9 10*s*. 0*d*.) [**1240**

The Intensity of Deformation during Rolling.
WUSATOWSKI, Z., *Prace Inst. Hutn.* (Poland), 1958, (2), pp.120–123; *Neue Hütte*, 1958, Aug., pp.494–497. (£2) [**1259**

Contribution to the Physical Investigation of Fatigue Damage.
WEISZ, M., *Rev. Mét.*, 1959 Jan., pp.83–103. (£8 15*s*. 0*d*.) [**1264**

Contribution to the Dynamics of Steel-making Processes.
HEISCHKEIL, W., and KOOTZ, T., *Stahl u. Eisen*, 1959, Feb. 19, pp.205–210. (£4 5*s*. 0*d*.) [**1265**

The Development of a Weldable Manganese-Titanium-Aluminium Alloyed Steel Quality St. 52 in Hungary.
KRISTÓF, G., *et al.*, *Neue Hütte*, 1958, July, pp.425–432. (£5 15*s*. 0*d*.) [**1291**

Comparative Investigation of Defects in Heavy Forgings by means of Ultrasonic Waves and the Betatron.
BRAND, L., *Stahl u. Eisen*, 1959, Jan. 8, pp. 32–36. (£3 10*s*. 0*d*.) [**1309**

Experience with a 15-MeV-Betatron used for the Non-destructive Testing of Steel Products.
KRÄCHTER, H., *Stahl u. Eisen*, 1959, Apr. 2, pp. 419–426. (£5) [**1312**

Critical Consideration of Mechanism and Automation in Steel Production.
HÜSER, K. H., *Stahl u. Eisen*, 1959, Jan. 22, pp. 65–73. (£6 10*s*. 0*d*.) [**1313**

Causes and Prevention of Surface Fissures of Hot-Worked Steel Products. I–Influence of Heating Conditions, Scaling Loss and Tramp Elements on the Surface Fissures.
OHTAKE, T., *et al.*, *Nippon Kinzoku Gakkai-Si*, 1957, Sept., pp.536–540. (£9 10*s*. 0*d*.) [**1316**

The Various Effects of Vacuum Melting on the Gas Content of Metals.
PFEIFFER, I., *Z. Metallk.*, 1958, Sept., pp.455–460. (£2 10*s*. 0*d*.) [**1317**

Electro-hydraulic Forging Press with Crank Drive Apparatus.
HERTL, A., *Stahl u. Eisen*, 1959, Apr. 16, pp.477–485. (£6 5*s*. 0*d*.) [**1318**

Consideration of the Chemical Attack on Refractories by Steel Baths during Metallurgical Processes.
COCCO, A., *Fonderia Ital.*, 1959, Feb., pp.47–51. (£4 5*s*. 0*d*.) [**1325**

Knurling or Grooving of Rolls.
NEUMANN, H., *Neue Hütte*, 1959, Apr., pp.244–246. (£3 10*s*. 0*d*.) [**1334**

Effect of Structure of Flux on Porosity of Weld.
PODGAETSKII, V. V., and MEL'NIK, A. V., *Avtom. Svarka*, 1955, (4), pp.58–62. (£2 5*s*. 0*d*.) [**1336**

Spectrographic Analysis of High-Silicon Aluminium Alloy and Welds.
DEM'YANCHUK, A. S., and RYABUSHKO, O. P., *Avtom. Svarka*, 1958, (10), pp.86–89. (£1 15*s*. 0*d*.) [**1347**

The Uses of the Electronic-probe Micro-analyser in Ferro-metallurgical Research.
PHILIBERT, J., and CRUSSARD, C., *Rev. Mét.*, 1956, June, pp.461–470. (£4) [**1353**

Recent Investigations on the Relation between the formation of the Chip and Tool Life when Turning Steel with Carbide Tips.
WEBER, G., *Stahl u. Eisen*, 1958, Nov. 13, pp.1678–1690. (£7 10*s*. 0*d*.) [**1355**

Preventing the Occurrence of Premature Cavitation in the Piercing of High-alloy Steels.
PLYATSKOVSKII, O. A., and PISHCHIKOV, G. P., *Stal'*, 1952, Apr., pp.330–336. (£5 10*s*. 0*d*.) [**1364**

Continuous Ultrasonic Testing of Products of the Iron and Steel Industry.
KOPINECK, H.-J., *et al.*, *Stahl u. Eisen*, 1959, May 28, pp.786–797. (£7 5*s*. 0*d*.) [**1365**

Investigations of Bessemer Converter Bottoms.
KÖHLER, W., *et al.*, *Stahl u. Eisen*, 1959, May 14, pp.674–683. (£6 5*s*. 0*d*.) [**1369**

Interaction between Steel and Moulding Material.
TROMMER, W., *Giesserei*, 1955, Aug. 18, pp.433–440. (£6 5*s*. 0*d*.) [**1370**

Crack Formation in Steels under the Influence of Aqueous Hydrogen Sulphide Solutions. *See also* No.1390.
NAUMANN, F. K., and CARIUS, W., *Arch. Eisenhütt.*, 1959, Apr., pp.233–238. (£4 15*s*. 0*d*.) [**1373**

First Blast-furnace Gas Turbine Plant at a German Steelworks.
MÜLLER-TRIMBUSCH, K., *Stahl u. Eisen*, 1959, Apr. 16, pp.457–463. (£5) [**1376**

Welded Gear Wheel Designs.
DZEN', V. I., *Svarochnoe Proizv.*, 1958, Jan., pp.19–21. (£3 15*s*. 0*d*.) [**1377**

Heat Transfer of Rolled Finned Tubes
GRASS, G., *Allgemeine Wärmetechnik*, 1956, (5/6), pp.104–108. (£3) [**1381**

Systematic Examination of the Heat Transfer and Resistance to Flow of Finned Tubes.
GRASS, G., and COENEN, F. P., *Atom-Kernenergie*, 1959, (2), pp.1–8. (£4 5*s*. 0*d*.) [**1382**

On the Determination of the Tensile Strength of Tubes in Ring Tensile Tests.
KRAVCENKO, C., *Arch. Eisenhütt.*, 1959, May, pp.311–314. (£3) [**1389**

The Significance of the Corrosion Processes in Aqueous Hydrogen Sulphide Solutions for the Formation of Cracks in Steels.
*See also No.*1373.
NAUMANN, F. K., and CARIUS, W., *Arch. Eisenhütt.*, 1959, May, pp.283–292. (£6 5*s*. 0*d*.) [**1390**

Limitations in the Evaluation of Gamma Radiographs used for Examining Circumferential Pipe Welds in Accordance with DIN 54 111.
PAPKE, W. H., *Schweissen u. Schneiden*, 1958, (11), pp.439–441. (£2 15*s*. 0*d*.) [**1391**

Design Principles for Cold Pressed Steel Components.
FELDMANN, H. D., *Konstruktion im Maschinen-, Apparate- u. Gerätebau*, 1959, (3), pp.82–89. (£4 5*s*. 0*d*.) [**1392**

The Activation Energy of the Process of Diffusion Creep in Disordered Substitutional Solid Solutions of Metals.
GEGUZIN, Ya. E., *Doklady, A. N.*, 1958, (4), pp.819–822. (£2 15*s*. 0*d*.) [**1398**

Hot Dip Aluminizing. (A review of events up to 1955; 146 bibliog. references.
HORSTMANN, D., *Stahl u. Eisen*, 1957, Mar. 21, pp.359–362; Apr. 4, pp.435–438; Apr. 18, pp.512–525. (£6) [**1404**

Arc Surfacing of Components Subject to Abrasion with Hard Alloys.
TYTKIN, M. A., *Svarochnoe Proizv.*, 1959, (5), pp.35–36. (£2 5*s* 0*d*.) [**1405**

Development Tendencies and Weldability of Modern Steels for Boilers, Container and Chemical Plant Construction.
ZEYEN, K. L., *Ind. Anzeiger*, 1958, June 27, pp.739–743. (£5.) [**1406**

Influence of Photo-synthesis on the Corrosion of Steel in Sea-water.
HACHE, A., *et al. Corrosion et Anticorrosion*, 1959, Feb., pp.56–62. (£3 5*s* 0*d*.) [**1407**

A Comparison between Low-carbon Austenitic Stainless Steels and St bilize Steels for Welded Apparatus in the Chemical Industry.
LÖFBLAD, B., and LINDH, G., *Internat. Inst. of Welding*, 1958, June 30, Vienna. (£5 15*s*. 0*d*.) [**1408**

The Behaviour at the Yield-point of Skin-passed Deep-drawing Steel Sheets after Ageing.
LUEG, W., and FUNKE, P., *Stahl u. Eisen*, 1959, July 9, pp.969–976. (£5 5*s*. 0*d*.) [**1411**

Means of Eliminating Stoppages in Sinter Plants. (Summary)
PRITYKIN, D. P., and DRIMBO, A. V., *Stal'*, 1958, Mar., pp.202–205. (£1 10*s*. 0*d*.) [**1416**

Utilization of Granulated Slags for Producing Heavy Panelling and Cast Partitions.
KHOKHOLEV, K. I., Ch.IV of book: Experience in the Use of Blast Furnace Granulated Slags in Structural Works. (From Russian.) (£6 15*s*. 0*d*.) [**1417**

The Influence of Charging Times and Storage at Room Temperature on the Hydrogen Embrittlement of Steels.
PLUSQUELLEC, J., *et al.*, *Compt. Rend.*, 1958, June 23, pp.3454–3457. (£1 15*s*. 0*d*.) [**1427**

ABSTRACTS OF CURRENT LITERATURE *Iron and Steel Manufacture and Related Subjects* AND BOOK NOTICES

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*Abstracts, the reference to which is marked with an asterisk are, or are to be made available as translations.

MINERAL RESOURCES

The world's largest lateritic iron ore deposit M. Moyal (*Min. J.*, 1959, **252**, Mar. 13, 284–285) A description of an orebody in Guinea.

Vares: Yugoslavia's biggest iron ore mine B. Djukic (*Min. J.*, 1959, **252**, Mar. 20, 311) Work on expansion started in 1951 and has just been completed.

Iron ore in the Soviet Union S. I. Tomkeieff (*Nature*, 1959, **183**, Apr. 11, 1028; from *Priroda*, 1958, **7**, 16) The geology of the Kursk region is briefly described and reserves are estimated. Production figures are given.

Iron ore in Canada A. Hopkins (*Mine Quarry Eng.*, 1958, Sept., 407–414) Locations and statistics are shown and the classification and chemical compositions of ores are reviewed.

Parallelism in mineral composition and chemical analysis for various types of iron ore with particular reference to marine-sedimentary iron ore deposits H. G. Siebdrat (*Arch. Eisenhut.*, 1959, **30**, Feb., 61–70) The relationship between mineral composition and chemical analysis has been established for (1) intrusive-magmatic iron ores from Kiruna, Gellivaara and Grängesberg, (2) marine-sedimentary ores from Peine-Ilsede, and (3) oolithic iron ores from four different deposits. The calculation of mineral composition from chemical analysis is advocated as being a valuable complement to the optical study of iron ores.—L.J.L.

The Frodingham ironstone bed 1859–1959 (*Appleby Frodingham News*, 1959, **12**, Spring, 16–24) The story of the rediscovery of the bed, a history of the workings and an illustrated account of the methods of working are given.

ORES—MINING AND TREATMENT

Methods of working in the iron ore mines of Lappland R. Mohan (*Trans. Min. Geol. Met. Inst. India*, 1957, **54**, Apr., 63–110) The development of longhole stoping and drilling methods are described, also loading and transport systems as workings increase in depth.

Bowne and Shaw quarries (*Mine Quarry Eng.*, 1958, Oct., 428–437) An illustrated account of operations at the limestone quarry worked by a subsidiary company of Stewarts and Lloyds.

Iron ore carrier developments P. Duff (*Shipping World*, 1957, Jan. 30, 155–160, reprint) Existing ships are listed and operating experience and port developments are reported. Outlook in view of the tendency to draw upon more distant sources of ore is discussed.

Carrying ore by submarine (*Min. J.*, 1959, **252**, Apr. 24, 443) A discussion of the possibility of carrying ore from Hudson's Bay throughout the year and notes on the Moby Dick now ready for construction.

Ore preparation, Part I (*Rec. Ind. Min.*, 1958, Dec. 15, Special Number, 1-211) After an introductory section the following subjects are dealt with; the presentation of results of a separation; the movement of solid bodies in a fluid; size classification; crushing and grinding.—A.G.

Milling plants in Canada: metallic ores (*Dept. Mines Techn. Surveys, Ottawa. Mineral Resources Operators List 3, Part I*, 1958, Jan., 26–30) A table of plants treating iron ores is given.

What is the optimum concentration to be aimed at in an ore washery? R. Duval (*Ann. Mines*, 1959, Jan., 43–51) The author applies the method developed in an earlier article (Nov., 1958, 710–762) using quality control graphs to determine the grade for which the concentrate gives the maximum washing yield in relation to crude tonnage.

Experiments in concentrating iron ore from the Pea Ridge deposit, Missouri M. M. Fine and D. W. Frommer (*Min. Eng.*, 1959, **11**, Mar., 325–328) Concentrates of from 6·0–7·4%Fe at recoveries of 89·9–97·6% were attained.

Effect of various compounds such as SiO_2, Al_2O_3, CaO, etc., on arsenic removal during ore beneficiation processes S. Sato (*Tetsu to Hagane*, 1958, **44**, Sept., 945–947).—K.E.J.

Some industrial applications of magnetic power T. J. Hawker (*Trans. Soc. Eng.*, 1959, **50**, Jan.–Mar., 17–29, discussion 29–35) Separators, lifting magnets, ore beneficiation and tramp iron extractors are reviewed.

Acid-ferrous sulphate leaching of low-grade manganese carbonate and oxide ores. Cuyuna Range, Minnisota H. Dolezal and H. C. Fuller (*U.S. Bur. Mines Rep. Investig.*, 5442, 1959, pp. 27).

Pressure drop in the fluidized roasting of pyrites cinder K. Okajima (*Tetsu to Hagane*, 1958, **44**, Sept., 937–938).—K.E.J.

Study of the charging process in the sintering test Y. Suzuki (*Tetsu to Hagane*, 1958, **44**, Sept., 938–940).—K.E.J.

On factorial experiment, practice and its effect on 'New Greenawalt' sintering plant T. Kitagawa (*Tetsu to Hagane*, 1958, **44**, Sept., 935–937) In a statistically designed experiment, the coke content, sintering time, suction pressure and choice of pan were varied at three levels, and correlations are made with FeO content, yield, cyclone dust, dust size, exhaust gas temp., and fan power.—K.E.J.

On the operating progress of Dwight-Lloyd type sintering plant in the Kokura steel works T. Sanematsu, Y. Mizobe, S. Kiriyama, and S. Saito (*Sumi. Met.*, 1958, **10**, Oct., 207–215) [In Japanese] Operating statistics are given for five years. Various improvements are described, and the greatest efficiency is for a two-year period on lime sinter.—K.E.J.

Effect of different ratios of mixture of raw materials on sintering T. Saito (*Tetsu to Hagane*, 1958, **44**, Sept., 943–945) Mixes were made of magnetite and limonite, in all ratios from 100% to 0, with additions of scale, cinder, etc. Regression lines are shown giving a linear relationship between magnetite content and sintering time, strength and yield, and between magnetite content and the reciprocal of sinter size.—K.E.J.

On the fundamental study of moisture in sinter raw mix and the practical method of its control T. Kitagawa (*Tetsu to Hagane*, 1958, **44**, Sept., 940–943) The effects of moisture on volume of raw mix, sinter yield and sinter size are investigated for variations of coke content and other parameters.—K.E.J.

Sintering plant expands blast furnace and open hearth capacity W. R. Corzilius (*Blast Furn. Steel Plant*, 1959, **47**, Jan., 44–50) A detailed description is given of the operation and control system of the sintering plant which went into production in 1958 in the works of the Granite City Steel Co., Illinois. It handles at more than 2500 tons per day.

Sponge iron production J. Grindrod (*Min. J.*, 1959, **252**, Feb. 13, 173–174) The Hyl process, developed in Mexico and using natural gas or petroleum and neither coal nor limestone, is outlined. A 200 t/day plant is working and estimates for a 500 t/day plant are given.

Statistical computations increase production M. J. Greaves (*Iron Steel Eng.*, 1959, **36**, Jan.,

99–102) The application of statistical production studies to steel plant studies and the use of computers in evaluation are discussed, and illustrated by a study of sinter plant data.

Desulphurization of Renn 'Luppen' in the solid state M. Wahlster and C. B. Schmidt (*Iron Coal Trades Rev.*, 1959, **178,** Feb. 27, 493–494; from *Tech. Mitt. Krupp*, 1958, **16,** June, 39–40) The 'luppen' or nodules produced may have up to 1%S and tests have been made to see whether some of this can be removed as a continuous operation before making into steel. A rotating kiln was used for (batch) testing taking 1 t nodules and lime and coke breeze, heating slowly to 1000°C and holding till sulphur was completely removed. With 100 kg lime and 25 kg coke S fell in 4 h from 1·1 to 0·25% and C from 0·45–0·13%. Desulphurization began at ~800°C and reached a maximum at 900–1050°C, sintering sets in at 1080°C. A continuous system was then constructed and 85% of the S was removed using 4 min nodules, larger sizes (about ¼ of the product) could be added to the blast furnace burden. The sulphur-rich lime layer could not be removed mechanically, but reabsorption was negligible in the electric furnace, and S was decreased to 0·06%. Further reduction could be effected with a suitable slag.

FUEL–PREPARATION, PROPERTIES AND USES

Fuel Efficiency in the iron and steel industry R. P. Towndrow (*J. Inst. Fuel.*, 1959, **32,** Mar., 106–109) A general account of directions which fuel economy has taken.

Fuel briquetting in the USA D. G. Madley (*United Kingdom Scientific Mission Memo. No.17/58*, 1958, Dec. 19, pp. 9) Data collected from visits to four plants are presented.

New possibilities for the dehydration of fines in the preparation of coal K. Lemke (*Glückauf*, 1959, **95,** Feb. 28, 293–298). The technically and economically greatest problem of German coal preparation is the dehydration of the fine sludges, a problem that was unknown ten years ago, and is still unsolved in spite of a number of new methods that were tested recently. The old conventional methods failed completely. These methods are briefly described.—T.G.

Improvement of coking coal quality R. M. von Storch (*Blast Furn. Steel Plant*, 1959, **47,** Jan., 42–43, 54) The operation is described of the new Wellington, Utah, coal cleaning plant of United States Steel Corp.

Coal handling at the Aliquippa works of Jones & Laughlin Steel Corporation C. L. Potter (*Blast Furn. Steel Plant*, 1959, **47,** Jan., 39–41, 50) The handling of coal is described from its receipt in barges from the mines of the Jones & Laughlin Corp. to its delivery to the coke ovens.

Papers on fuel technology and other subjects presented at the Annual Meeting of the American Society of Mechanical Engineers in New York City Nov. 30–Dec. 5, 1958 D. G. Madley (*United Kingdom Scientific Mission Memo. No.20/58*, 1959, Feb. 13, pp. 9) **The aerodynamic approach to furnace design** J. H. Chesters (1) The use of models for studies on the flow pattern, mixing, and flux deposit in OH and other furnaces is described, with findings **Use of flow models for boiler furnace design** R. W. Curtis and L. E. Johnson (2) **Use of models for studying pulverized-coal burner performance** G. C. Whitney (2) **Coal cleaning in relation to sulphur reduction in steam coals** H. J. Rose and R. A. Glenn (3) **The compacting process, a method of particle agglomeration** H. D. Vanderlip and G. J. Jennrich (6) An account of the 'Compactor' mill and tests on the granulation of NaCl are given **A radiotracer counting method for engine wear determination** E. H. Okrent and G. A. Weisgerber (8–9).

Improving Foundry Coke (*Castings*, 1959, **5,** Feb., 7, 9) Notes on a symposium are given. Size and strength of coke and cupola performance are very briefly discussed and addition of Diesel oil to the charge is shown to improve coke properties.

The B.C.R.A. Coke Research Centre (*Coke Gas*, 1959, **21,** Apr., 134–141; *Gas World*, 1959, **149,** Apr. 11, 698, 701, 702, 705, 706) Illustrated descriptions.

The process of fissuring in coke and the mechanism of coke formation J. Nadziakiewicz (*Coke Gas*, 1959, **21,** Feb., 46–55).

Iscor Works, Vanderbijlpark (*Coke Gas*, 1958, **20,** Nov., 446–453) A detailed account of the coking plant is given.

Preparation of metallurgical coke M. Turkovich and E. F. Burch (*Blast Furn. Steel Plant*, 1959, **47,** Jan., 34–38) The various types of equipment used for coal preparation before shipment are described, and their applications illustrated by an account of the coal preparation plant used by the Island Creek Company at their Virginia mines.

Influence of the ash content of coal on the cost of the coke and (crude) pig iron, and influence of coal moisture on the cost of the coke P. S. Bakels (*Inst. Nac. Carbon Bol. Inf.*, 1958, **7,** July/Aug., 141–170).

Olefine and benzole formation in coke ovens J. Ewers (**Brennstoff-Chem.*, 1955, **36,** Feb. 9, 33–7) A report of a lecture. Better yields of ethylene and benzene are obtained when mineral oil is injected into the gas space of the oven instead of mixing it with the coal. By choice of temperature and the legnth of stay in the reaction space either olefine or aromatics production can be favoured. Time can be regulated either by control of throughput or by use of a carrier gas; longer times favour aromatics formation.

Factors affecting the biological treatment of carbonization effluents J. W. Abson and K. H. Todhunter (*Gas World*, 1959, **149,** Apr. 4, 61–70, 72).

AIR POLLUTION AND SMOKE

The purification of steelworks fumes L. Septier and P. Leroy (*Publ. IRSID*, 1958, Series A, (194), Dec., pp. 47). After discussing the characteristics of fumes, the methods of collection, cooling and cleaning by wet and dry processes are described. Factors governing the choice of process are discussed. (29 refs). Properties of steelworks fumes are tabulated in an appendix.–A.G.

Contribution to the calculation of electro-precipitators J. Böhm (*Research Institute in Air Handling Equipment, Prague, selected articles*, 1958, (1), 8–41) [in English] A modified Deutsch formula is derived and used to compare calculated and measured separation efficiencies. Though experimental data are limited agreement appears to be satisfactory.

Air pollution and its measurement T. Petryšin (52–85) [In German] Dust content measurements near a large power station are considered. A simple method of measurement with examination of the dust particles is described and correlated with meteorological conditions.

Dust precipitation by sonic and ultrasonic vibrations A. Willner (*Bergbau-Technik*, 1955, **5,** (4), 201–209) Theory and equipment are reviewed, and technical and experimental plant is described. Future developments are foreshadowed.

REFRACTORY MATERIALS

Steel plant refractories in Russia K. Shaw (*Iron Steel*, 1958, **31,** Dec., 593) A review of a conference on steel plant refractories held in Russia in July 1958, dealing very briefly with a large number of details.—T.G.

Practical test of special silica bricks. Silica bricks containing Cr_2O_3 K. Isoda (*Tetsu to Hagane*, 1958, **44,** Sept., 1012–1014) 'Sikron' and silica bricks are compared, as to chemical composition, refractory properties, and changes of these under various test conditions.

Relation of properties of high-aluminous roof bricks and conditions of steelmaking. Study on the roof of electric arc furnace made of high-aluminous brick I. S. Niwa (*Tetsu to Hagane*, 1958, **44,** Sept., 1018—1020) Details are given of the bricking pattern and of the chemical and refractory properties of four types of brick used. The relationship between roof life and ratio of high-alloy to total heats follows no pronounced pattern.—K.E.J.

Effect of minor additions on sintering of MgO G. K. Layden and M. C. McQuarrie (*J. Amer. Ceram. Soc.*, 1959, **42,** Feb., 89–92) Effects of Li, Na, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Zr, Ba, Ta and W, are reported. Cr inhibits sintering, most produce increased density but Ta, W, Ba and Ca had little effect on densification and W produces disruption (by compound formation) at ~1200°C. V has a considerable effect.

Problems in the production of sea-water magnesite W. C. Gilpin (*Refract. J.*, 1959, **35,** Jan., 4–12, discussion 13–14).

Clay lengthens pig mould life (*Iron Age*, 1959, **183,** Jan. 15, 83) The successful use is described of a mixture of clay and carbonaceous materials in place of lime for coating pig casting moulds.—A.G.

IRON AND STEEL—GENERAL

Developments in the iron and steel industry during 1958 I. E. Madsen (*Iron Steel Eng.*, 1959, **36,** Jan., 112–158) A detailed survey is given, mainly but not exclusively referring to US plants, of production in 1958, and development programmes in the fields of iron and steel manufacture and processing, and related equipment.

Impressions of the Polish iron and steel industry C. Knight (*E.S.C. News*, 1959, **12,** (4), 4–9) An illustrated account of an exchange visit.

Soviet steel—Expansion and research R. Sewell (*Brit. Steel.*, 1959, **25,** Feb., 52–57) A review of Soviet plans and developments in iron and steelmaking plants and techniques, reference being made to developments in welding processes (14 refs.).

Tata's two-million-ton project (*Tisco*, 1959, **6,** Jan.) **Role of Kaiser Engineers** (1–14) **Shipping and clearing at Calcutta** (15–23) **Construction at Jamshedpur** (24–68) An illustrated description.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The new giant in the valley J. M. Stapleton and D. H. Regelin (*Blast Furn. Steel Plant*, 1959, **47,** Jan., 55–61) An account is given of the rebuilding and modifications of No.3 Carrie blast furnace at the Homestead District Works of United States Steel Corporation. The rebuilt furnace has a 28 ft hearth diameter, and has been extensively modified.

Review of the iron making operation at Yawata works after the war and its prospects for the future K. Tsujihata (*Tetsu to Hagane*, 1958, **44,** Sept., 958–960).—K.E.J.

Soviet blast furnace practice J. H. Strassburger (*J. Met.*, 1958, **10,** Nov., 721–723) A description is given of blast furnace and sintering operations at the Kuznetsk and Zaporozhstal works, covering current practice and future plans.—A.G.

On the high humidity operation of a blast furnace E. Sakamoto (*Tetsu to Hagane*, 1958, **44,** Sept., 956–958) Furnace operating results show that moisture in the blast (10–30%) increases output and blast temp., and reduces coke rate.—K.E.J.

On the progress of recent practice of blast furnace in Kawasaki iron works, Nippon Steel & Tube Co. Ltd T. Tamada (*Tetsu to Hagane*, 1958, **44,** Sept., 949–951).—K.E.J.

Study on burden transit with radioactive isotopes. II. The transit time at different positions of the furnace S. Komaki (*Tetsu to Hagane*, 1958, **44,** Sept., 960–962) Studies using the ^{60}Co technique show transit times between 8½ and 13 h.—K.E.J.

An investigation of gas flow in a small blast furnace H. W. Hosking, W. O. Philbrook, and N. B. Melcher (*Trans. Met. Soc. AIME*, 1959, **215,** Feb., 96–103) Rates and patterns of gas flow were measured in an experimental blast furnace by determining gas compositions and temperatures, and by direct measurement of gas transit time using Hg vapour as a tracer.

A mercury-vapour method for the study of gas movement in the blast furnace H. W. Hosking, W. O. Philbrook, and N. B. Melcher (*Trans. Met. Soc. AIME*, 1959, **215,** Feb., 104–110) The technique is described of using Hg vapour as tracer to investigate rates and patterns of gas flow in blast furnaces. A pulse of Hg is injected into the hot blast. The method of measurement is described.

Permeability to gas in the Blast Furnace, and utilizing a German-type gas sampler Y. Imao (*Tetsu to Hagane*, 1958, **44,** Sept., 947–949) Measurements of shaft-gas analysis, temperature, pressure and velocity, were made in five concentric zones between the centre and the walls, for 100% raw ore and 100% self-fluxing sinter burdens. The patterns obtained are compared with the permeability and reducibility of the burdens.—K.E.J.

Distribution of blast furnace burdens in the furnace-top charging equipment and the charging level M. Yamamoto (*Tetsu to Hagane*, 1958, **44,** Sept., 954–956) Varying patterns of Dungun ore, sinter and limestone (including inclined distributions) were placed on the bell, and the distributions in the furnace are followed.

An experiment on Cr-elimination in the 1-ton experimental blast furnace C. Nakane (*Tetsu to Hagane*, 1958, **44,** Sept., 971–973).

Where there's iron there's a furnace (*Far East Trade*, 1959, **14,** Mar., 353) Illustrations of Chinese home-made furnaces with brief commentary.

The use of self-fluxing sinter J. S. McMahan (*Blast Furn. Steel Plant*, 1959, **47,** Jan., 51–54) Operating data for the use of self-fluxing sinter at the plant of the Steel Company of Canada showed that iron production of an 18 ft blast furnace was increased by over 40%, coke rate being lowered by 26%. These results were achieved without additional capital investment.

The making of self-fluxing sinter and the blast furnace operation with 100% sinter burden K. Kasai (*Tetsu to Hagane*, 1958, **44,** Sept., 951–954) The mix consisted of 34·8% pyrites cinder, 31·0% imported ore, 15·2% limestone and amounts of mill scale, iron sand and Mn ore. Details are given of the sinter size and strength, and of the furnace operation using this burden.—K.E.J.

Works trial with 95% sinter on No.7 Seraing blast furnace of the Société Cockerill-Ougrée A. Firket and J. Molderez (*Rev. Univ. Min.*, 1959, **15,** Feb., 93–106) A report is given of a 95% sinter trial on a 5 m dia. blast furnace of S. A. Cockerill-Ougrée. The properties of the sinter, details of the trial and the technical and economic results are discussed in detail.

Effect of iron-ore pellets on blast-furnace practice and a review of industrially employed pelleting methods K. Meyer (*Stahl Eisen*, 1959, **79,** Feb. 19, 222–225). The author estimates that about 17×10^6 tons of pellets per year are used all over the world and reviews the beneficial effects on blast-furnace practice and compares the various methods employed in the production of the pellets.—T.G.

Heat balances and blast furnace coke rates A. Poos and A. Decker (*Rev. Univ. Min.*, 1959, **15,** Jan., 19–32) A method of calculation is presented which permits the prediction of coke rates and the expression of each factor in terms of kg of coke. Practical examples are given illustrating the application of the method.—A.G.

Kinetics of iron ore reduction W. M. McKewan (*Trans. Met. Soc. AIME*, 1958, **212,** Dec., 791–793) A note. A formula connecting the initial radius of a sphere of iron ore, its density, the fractional reduction, time, etc., is derived and compared with the published results of reduction kinetics.—T.G.

Static control provides blast furnace automation N. J. Behne, H. C. Diener, jun., and J. R. Erbe (*Iron Steel Eng.*, 1959, **36,** Feb., 127–138) The principle and details of the operation of the automatic charging system installed for No.4 blast furnace of the Youngstown works of United States Steel Corp. are described and discussed.

Development of a hot-filter for the purification of top gas from a low-shaft furnace operated with bituminous coal W. Fuchs and H. Weyerstrass (*Forsch. Wirts. Nordrhein-Westfalen, No.400*, 1958, pp. 75) The bituminous coal used in the low-shaft furnace produces a top gas that contains large proportions of tar among other impurities. This gas cannot be purified by conventional methods as it tends to polymerize. It must therefore be cracked, preferably on materials that can later be charged into the furnace. The hot gas is heated further and led through a mixture of iron ore where it cracks, at the same time reducing the ore to a certain extent. This will save coal when the ore is charged. The results of the tests are reported in detail.—T.G.

High voltage rectifiers in the iron and steel industry E. Hanson (*Metro. Vick. Gaz.*, 1958, **29,** Nov., 293–297) Blast furnace gas-cleaning plant is described.

Problems and possibilities of iron ore smelting B. Marincek (*Elektrowärme*, 1959, **17,** Feb., 29–31) The blast furnace requires high quality coke but electric smelting uses half the quantity of coal of practically any quality. To reduce the consumption of power, pre-smelting with fines can be employed which doubles production and halves the electricity needed.

Studies on electric pig iron smelting of iron sand. II. Influence of reducing conditions on the composition of the pig iron Y. Sato (*Tetsu to Hagane*, 1958, **44,** Sept., 962–963).—K.E.J.

Smelting of iron sand agglomerates in the open type electric furnace Y. Kusajima (*Tetsu to Hagane*, 1958, **44,** Sept., 967–969) The furnace is described, and the smelting practice employs agglomerates, coke breeze, limestone and degraded SiC. The power consumption is less with lower degrees of oxidation of the agglomerate.—K.E.J.

Electric furnace smelting of East Texas iron ores—A progress report H. Kenworthy and A. G. Starliper (*US Bur. Mines Rep. Invest.* 5427, 1958, pp. 12) The ores contain $< 25\%$Fe but laboratory tests show that a high recovery is possible and the iron formed is suitable for steel production by standard methods. Recoveries exceeded 95% while commercial mineral dressing recoveries were only 50% as a 45–50%Fe concentrate.

Kennecott dedicates the Hayden smelter C. D. Michaelson (*Eng. Min. J.*, 1959, **160,** Jan., 102) A plant producing sponge iron and H_2SO_4 from pyrites waste is briefly considered. The article is the substance of the address at the opening.

Direct reduction of iron ore R. R. Rogers (*Dept. of Mines and Techn. Surveys, Ottawa Inf. Circ.*, IC 109, 1958, Oct., pp. 11) An outline of the present status of direct processes with brief reviews of the H-iron, Madaras, Wiberg-Soderfors, Stelling, R-N, Kalling, Strategic-Udy and Krupp-Renn processes.

Direct iron ore reduction P. E. Cavanagh (*J. Metals*, 1958, **10,** Dec., 804–809) Interest in direct reduction processes has revived in recent years due to rising scrap costs and the high cost of new capital equipment, together with the increasing availability of lower-grade ores and the necessity for treating fines. Some commercial processes are described.

Iron by direct reduction J. Grindrod (*Min. Mag.*, 1959, **100,** Feb., 73–78) An account of the Strategic-Udy process as worked at Niagara Falls, with thermal data and an estimate of costs.

Iron reduction process (*Mod. Castings*, 1958, **34,** Nov., 4–5). A note on the Strategic-Udy process.

Here's direct reduction process for small plants (*Steel*, 1958, **143,** Dec. 1, 78–80) The Hyl process is described; it is a commercial method of direct reduction of iron ore to sponge iron for charging to electric steel-making furnaces. A 200 t per day plant is operating in Mexico and larger plants are planned. Ore is reduced in fixed-bed batch-type reactors by re-formed gas made from natural gas. Advantages are: alternative to blast furnace; coke and limestone not necessary; low capital investment; small scale possible; ore fines can be handled.—D.L.C.P.

Mains-frequency induction crucible furnaces in the new Ford Co. of Brazil, Sao Paulo, foundry H. Rohn (*Elektrowarme*, 1959, **17,** Feb., 42–44) The reasons for the choice of this type of furnace are given and three are installed producing 75–80 t/day of iron on two-shift operation. The capacity of each is 8000 kg with a load of 4200 kVA. The operation, grades of iron produced, and control system are also described.

PROPERTIES, TREATMENT AND USE OF SLAGS

Density of solid blast-furnace slag (*Iron Coal Trades Rev.*, 1959, **178,** Feb. 6, 327) Methods of making dense slag suitable for road making and railway ballast are considered. A winnowing device for separating dense and porous slag is being developed by BISRA.—A.G.

Separation of blast-furnace slag (*Found. Trade J.*, 1959, **106,** Feb. 19, 212) A note on the BISRA separator for the production of dense and porous fractions.

Slag recovery at Yawata works K. Wada (*J. Met.*, 1959, **11,** Mar., 187–188) Beneficiation of the OH slag produced in this works and its utilization in the sinter plant are described.

Activity of oxygen and constituents in magnesia-saturated lime-iron oxide slags S. Shimada (*Tetsu to Hagane*, 1958, **44,** Sept., 1070–1072) Graphs show the effect of CO/CO_2 mixtures and other gases on the equilibria, and the oxygen pressure and activities of FeO and Fe_2O_3 at 1500°C.—K.E.J.

PRODUCTION OF STEEL

Iron and steelmaking with special reference to the technology of oxygen steel J. L. Harrison (*Inst. Hierro Acero*, 1958, **11,** Oct.–Dec., 229–257) Commencing with a brief review o the history of the development of the iron and steel industry in Spain, the author describes the principal iron and steelmaking processes, with particular reference to the use of oxygen, and concludes with a discussion of the possible applications of these processes in Spain (38 refs.).

Automatic processes in the production of steel W. H. Dauberman (*Blast Furn. Steel Plant*, 1959, **47,** Jan., 72–78) Automatic processes in sintering, blast-furnace charging, and soaking pit and rolling mill control are outlined.

Buildings for iron and steelworks. Discussed at BISRA Conference (*Engineering*, 1959, **187,** Feb. 13, 220–221) Abstracts are given of the following: **Foundations to iron and steel works buildings** W. S. Atkins **Some notes on iron and steel works buildings at Corby works** T. E. Clements **Some notes on modern steel works structures** E. F. Wooldridge and N. Lancaster **Load distribution through melting shop stage and gantry rail maintenance** D. B. Wilson **Superstructures to iron and steel works buildings** K. F. Geesin **Iron and steel works buildings** E. Ibbotson **The framework of buildings used in the iron and steel industries in France** A. Delcamp **Examples of iron and steel works buildings in Germany** G. F. Drath **Research and development in relation to buildings and structures in the iron and steel industry** J. S. Terrington, D. Buchanan, and P. D. Thompson **Architectural aspects of iron and steel works buildings** F. Gibberd.

Control engineering in a steelworks M. Thomas (*Process Control Autom.*, 1959, **6,** Feb., 50–55) Instrumentation of OH, reheating and continuous furnaces and soaking pits and of melting shops and rolling mills is considered and illustrated with block diagrams.

Statistical techniques R. V. Wallach (*Engineer Foundryman*, 1959, **24,** Feb., 48–52) Uses in the steelworks are described. Sampling and analysis, defects in rolled products as related to operating variables in steelmaking and rolling, strength of plates, dimensions of cut sheets, and the saving of material by improved shearing length control are considered.

On deoxidation reaction by vanadium in molten steel and its equilibrium constant H. Sawamura (*Tetsu to Hagane*, 1958, **44,** Sept., 1030–1031).—K.E.J.

On sulphur restoration caused by chromium elimination, and its remedy K. Maeda (*Tetsu to Hagane*, 1958, **44,** Sept., 973–975) The results illustrate the linear relationships between *S* and (FeO), and between the weight of sulphur restored and the oxygen used from oxidizing Si, Mn, and Cr.—K.E.J.

Tonnage oxygen for steelworks (*Overseas Eng.*, 1959, **32,** Apr., 294–297) A review, with an account of the systems used by British Oxygen and Air Products (Great Britain) Ltd.

The utilization of tonnage oxygen in recent steel-making processes M. Doi (*Tetsu to Hagane*, 1958, **44**, Sept., 1023–1026) Trends in general furnace operation (oxygen consumption, fuel consumption, melting time, production rate and iron ratio) over the period 1950–1958 are examined, and details are given of test utilization of tonnage oxygen.

Steel Company of Wales. Third development plan raising capacity to 3 m ingot tons (*Financial Times*, 1959, Feb. 4, 13) **Architecture of today. No.462. Constructional work at Port Talbot** A. T. Edwards (14–15) An account, with illustrations, of the buildings in course of erection.

The expansion program at Sparrows Point G. C. Little and J. M. Tillman (*Iron Steel Eng.*, 1959, **36**, Feb., 69–84) Recent developments at the Sparrows Point plant of the Bethlehem Steel Co. are described. They include increased ingot production and slab rolling capacity, with additional electrical equipment.

Jones & Laughlin: Cleveland Works T. J. Ess (*Iron Steel Eng.*, 1959, **36**, Feb., 86–104) A description is given of the iron and steel-making and steel processing plants at these works.

Standard steel works installs facilities for specialty steel (*Iron Steel Eng.*, 1959, **36**, Feb., 158) Installation is described of an electric furnace, and of ingot-cooling and heat-treating furnaces and of an X-ray spectrometer at the Standard Steel Works Division of Baldwin–Lima–Hamilton Corp.

Billets and Bessemers H. McC. Lawrence (*Eng. Found.*, 1959, **24**, Feb., 43–47) Design and installation of a steelmaking plant on a site of 13 000 ft² is described. Two 3½-t side-blown converters were used and the plant produced up to 50 t of ingots per 9 h shift. The analytical control is described in detail.

Preliminary experiments on the elimination of chromium from molten pig iron by Bessemerizing T. Souma (*Tetsu to Hagane*, 1958, **44**, Sept., 970–971) Results are given for the variation of efficiency and velocity of Cr reduction with bath temp., and for the distribution of oxygen between Si, Mn, Cr and C, at different temp.—K.E.J.

A study on the dephosphorization equilibrium in oxygen converters Application of Schenck's equilibrium formula and Herasymenko's ionic method E. Homma (*Tetsu to Hagane*, 1958, **44**, Sept., 1063–1065).—K.E.J.

Study on a permanent wall type furnace with forced cooling. IV. Experimental operation of the water-cooling converter R Sato (*Tetsu to Hagane*, 1958, **44**, Sept., 1065–1067) Compositions of slag and metal at charging and at the end of various heats are given. Variations of water temp. with blowing time are shown on graphs.—K.E.J.

Flow in the slant top-blowing converter H. A. Hasimoto (*Tetsu to Hagane*, 1958, **44**, Sept., 1055–1056) Flow patterns in the gas and liquid are shown for various slant angles and angles of asymmetry of the jet.—K.E.J.

Model experiments on the profile and operation of the L.D. converter M. Shimada (*Tetsu to Hagane*, 1958, **44**, Sept., 1056–1058).

Study of dephosphorizing reactions with the 5-t experimental oxygen converter S. Maehara (*Tetsu to Hagane*, 1958, **44**, Sept., 1058–1060).

Study of nitrogen in steel with the 5-t experimental oxygen converter in Yawata works S. Maehara (*Tetsu to Hagane*, 1958, **44**, Sept., 1060–1062).—K.E.J.

Study of oxygen and sulphur in steel with the 5-t experimental oxygen converter S. Morita (*Tetsu to Hagane*, 1958, **44**, Sept., 1062–1063).—K.E.J.

Oxygen steelmaking Head Wrightson & Co. Ltd (*Pamphlet*, 1959, Feb., pp. 28) The oxy-Thomas, L.-D. and Kaldo processes are reviewed.

The L.D. process D. Flament (*Mét. Constr. Mecan.*, 1959, **91**, Feb., 79–82) Technical and economic considerations in relation to the L.D. process are outlined, and the present world L.D. capacity is tabulated.

Steel melting plant at Aviles, Spain (*Engineer*, 1959, **207**, Feb. 6, 236–237) The new OH shop with 350-t tilting furnaces and 600-t mixer is described.

The new melting shop of ENSIDESA at Aviles (*Brit. Eng.*, 1959, **41**, Mar., 280–281) An illustrated account of the new O.H. shop of the Empresa Nacional Siderurgica S.A. and the equipment supplied and erected by members of M.E.E.C.O.

A note on physical chemistry and the practice of steelmaking B. M. Larsen (*Iron Coal Trades Rev.*, 1959, **178**, Jan. 30, 269–270) A brief discussion of the lag of theory behind practice and the consequences of this condition such as the economics of slag run-off practice and the foaming of slag.

Fundamental research on combustion in the OH furnace M. Yamamoto (*Tetsu to Hagane*, 1958, **44**, Sept., 1020–1022) Relationships between secondary air and oxygen in the waste gas, air and oxygen in the waste gas during charging, furnace pressure and oxygen in the waste gas during melting using oxygen, etc., are examined graphically and statistically.—K.E.J.

Factors affecting fuming in open-hearth furnaces C. Holden (*JISI*, 1959, **193**, Oct., 93–102) [This issue]

Application of oxygen to basic open-hearth production of killed steel M. Ito (*Tetsu to Hagane*, 1958, **44**, Sept., 1026–1028) Operating results given include metal analyses at various periods, times of operations, changes in slag composition after hot metal, the relationship between $V_{P_2O_5}$ [= (CaO)—1·57 $(P_2O_5)/(SiO_2)$] and (P)/[P] and (s)/[s] at melting and refining, and the relationship between [C] and (Σ Fe) at melting.—K.E.J.

On the reconstruction of a Siemens furnace S. Shimizu (*Tetsu at Hagane*, 1958, **44**, Sept., 990–992).—K.E.J.

Construction and operation of an OH furnace with all-basic roof S. Tamamoto (*Tetsu to Hagane*, 1958, **44**, Sept., 1014–1016).

Progress on the construction of the open-hearth furnace roof M. Takamuku, K. Okamoto, and S. Tamamoto (*Sumi. Met.*, 1958, **10**, Oct., 216–223) Operating, construction and repair practices over a period of years, with zebra, box and all-basic roofs are reviewed. Roof lives increased despite high oxygen consumption and higher outputs on cold charge.—K.E.J.

Some studies on an open-hearth furnace with an all-basic roof T. Yamaguchi (*Tetsu to Hagane*, 1958, **44**, Sept., 1007–1009) Operating results are given for two 60-t and one 120-t stationary furnaces. Other results include the relationship between S% in the product and CaO used for refining, the relationship between [Cr] and total Fe, fuel performance, brick behaviour and slag composition in the pocket.—K.E.J.

A fundamental investigation of chrome-magnesite brick after service in the roof of a basic open-hearth furnace T. Hayashi (*Tetsu to Hagane*, 1958, **44**, Sept., 1010–1012) The furnace had made 120 heats. Five zones behind the hot face are examined for changes of composition, X-ray patterns of the zones and matrices, and refractoriness-under-load.

Heat losses through the open-hearth furnace roof M. Kurita (*Tetsu to Hagane*, 1958, **44**, Sept., 1016–1018) Details are given of the quantity of radiation, surface temp. and residual brick length for various portions of the roof.—K.E.J.

Automatic combustion control for a gas-fired open-hearth furnace. I. Layout of automatic combustion control for a gas-fired open-hearth furnace T. Sakurada (*Tetsu to Hagane*, 1958, **44**, Sept., 1022–1023).—K.E.J.

Pre-refining steel for electric furnaces Brymbo Steel Works Ltd (*Engineer*, 1959, **207**, May 1, 685–687) A process of pre-treatment in which Si and P are removed by oxygen-lancing and powdered lime or limestone treatment is described, the carbon being left for the final decarburizing treatment.

Electric melting of steel H. W. A. Waring (*Financial Times*, 1959, Jan. 27, 6) **High-frequency type furnaces** F. Lowe (6) **Modern arc furnace design** A. G. Robiette (7) **Mains frequency steel making** W. Kelsey (7).

Installation and Commissioning of an 80-t electric arc melting furnace P. M. Thomas and A. Macnaughton (*J. West Scotland I.S.I.*, 1959, Paper 519, pp. 34) A complete account of the planning, layout, civil engineering, electrical equipment, fume extraction plant, installation and quantometer analysis is given.

Operation control adopted to decrease hydrogen content in molten steel in the basic arc furnace procedure M. Nishigishi (*Tetsu to Hagane*, 1958, **44**, Sept., 1043–1045).—K.E.J.

On the reaction velocity of decarburization in the steel bath of some basic electric furnaces K. Ikeda (*Tetsu to Hagane*, 1958, **44**, Sept., 1028–1030) Rate constants are obtained by two methods from results on 6-t and 30-t Héroult furnaces and on a 10-t Lectromelt furnace.—K.E.J.

A computer for controlling the parameters of an arc furnace Yu. E. Efroimovich, A. N. Kotikov, Ya. F. Stiop, E. S. Genishta, and V. B. Tikhmenev (**Elektrichestvo*, 1958 (5), 15–20).

High yield stainless steel ingots (*Iron Steel*, 1959, **32**, Jan., 27–31) The new plant laid down by Spartan Steel and Alloys Ltd at Birmingham is described, and processes used to obtain a high yield at the plant are discussed.

Mechanically-capped steel ingots H. Kajioka (*Tetsu to Hagane*, 1958, **44**, Sept., 981–983).—K.E.J.

Study of exothermic mixtures. III. Properties and applications of sleeve-type exothermic compounds K. Kakiuchi (*Tetsu to Hagane*, 1958, **44**, Sept., 975–978).—K.E.J.

Study on exothermic hot tops (Foseco Feedex). II. Saving of hot-topping quantity and shapes of hot-tops K. Sakai (*Tetsu to Hagane*, 1958, **44**, Sept., 978–979).—K.E.J.

Effect of the track time on the segregation of rimmed steel ingots T. Ooka (*Tetsu to Hagane*, 1958, **44**, Sept., 985–987) The degree of sulphur segregation at the top central axis of the bloom is related to the delay in solidification caused by early track times. Calculated curves for temp. against time from casting to drawing are given.—K.E.J.

Experiments in the production of semi-killed steel G. Leiber and D. Schauwinhold (*Forsch. Wirts. Nordhein Westfalen*, 1958, No.552, pp. 28) Four trials were carried out in which ~140 t of St 48 steel were poured as semi-killed steel. Some ingots were examined for structure, the remainder were rolled, and inspected for surface condition and yield. With an Si content of about 0·05% an Al addition of 20 to 40 g/t of steel produced the desired ingot structure. Subsurface blow-holes were formed when too little Al was added, and too much Al gave rise to a cavity which reduced the yield. The correct addition gave steel with a good surface and a yield corresponding to that from a rimmed steel.

Study on semi-killed steel ingots Relation between degree of deoxidation and inner quality of semi-killed steel ingots H. Kunitake (*Tetsu to Hagane*, 1958, **44**, Sept., 979–981).

Twin strand continuous casting (*Eng. Found.*, 1959, **24**, Feb., 37) A brief account of the Barrow installation.

Progress in the continuous casting of steel (*Eng. Dig.*, 1959, **20**, Jan., 41–44, 34) A review of development in the UK, in Europe, and in Russia.

The origin of sand marks. (The study of non-metallic inclusions.—V) M. Kawai and H. Kimura (*Tetsu to Hagane*, 1958, **44**, Nov., 1273–1279) Sand marks in rolled rods are traced back to the ingots. The sand marks are not changed macroscopically during heat-treatment. The ingot defects considered are non-metallic inclusions, blow holes, pin holes and cavities, etc.—T.G.

PRODUCTION OF FERRO-ALLOYS

Ferro-alloys and alloy steels (*Met. Bull.*, 1958, Nov. (Special Issue, 1–106) **Ore requirements** (17, 19, 21, 22, 25, 26) Mn, Cr, Mo, W, V, Nb, Ti and Zr sources and prospects are briefly surveyed **The UK ferro-alloys industry** T. J. Tarring (27, 29–31) The positions of Fe–Si, Fe–Mn, Fe–Cr and Fe–W are considered **The Norwegian industry** O. Knudsen (33–36) Ferrosilicon is reviewed and the general background of the Norwegian industry **The ferro-alloys industry of Sweden** H. Willners (37, 40, 41) Statistics are given and a list of producers **The ferro-alloy industry in**

France Chambre Syndicale de l'Electrometallurgie et de l'Electro-chimie (43, 44) A brief review with statistics of steel output **Ferro-alloy industry in Italy** Ferroleghe Unione Produttori Italiani (47, 49) Statistics and a list of producers and of products are given **World ferro-alloys directory** (52–57) **US ferro-alloy industry** J. C. Vignos (61–63, 65) Brief reviews of Fe–Mn, Fe–Si, Fe–Cr and its classification are given, with a table of imports and a note on electric furnace developments **The role of the ferro-alloy merchant** J. D. Proctor (67, 69) **The use and manufacture of blast furnace ferro-manganese** (73–74) A brief survey of effects in steel, ore sources and operating conditions **The use of manganese in steel** D. F. McVittie (75, 77, 78) **Chromium in special steels** A. M. Sage (79, 81, 85) Ferrochrome production is briefly discussed also **Silicon and steel** (87–89) **Nickel in special steels** Mond Nickel Co. (91, 94) **Cobalt in steels and ferrous alloys** Cobalt Information Centre, Brussels (95–96) **Tungsten** P. S. Bryant (97–99) W powder and carbide are also briefly considered **Molybdenum: Strategic and industrial asset** B. Jones (100–101, 105). **Vanadium in steels** A. F. Sprankle (103–105) **A glimpse of history** (106–107) An account of the ferro-silicon market in the late 1920's and the part played by C. Tennant Sons & Co. in the establishment of production at Bjølvefossen in Norway.

[Iron removal in] high nickel pig iron in the production of ferro-nickel R. Hirasawa (*Tetsu to Hagane*, 1958, **44,** Sept., 963–965) Increasing amounts of oxygen blown reduced the iron content at 1400 ± 50°C, and led to increased recovery of (Ni + Cr). For the same oxygen rates, increasing additions of SiO_2 increased the (Ni + Cr) content of the metal, but tended to reduce the recovery.—K.E.J.

FOUNDRY PRACTICE

Compressed-air economy in foundries A. Lindecke (*Giesserei-Techn.*, 1958, **4,** Oct., 253–258) A number of recommendations are given on how to economize in the consumption of compressed air. It is pointed out that in many cases it is considerably cheaper to use electric instead of compressed-air tools.—T.G.

New ingot-mould foundry for Sheffield (*Found. Trade J.*, 1959, **106,** Jan. 29, 117–119) An illustrated account of the new Brightside foundry at Ecclesfield **Brightside's new ingot mould foundry** (*Brit. Steel*, 1959, **25,** Jan., 20–21) A description of the equipment and operation of the new 25000-t per annum ingot mould foundry of the Brightside Foundry and Engineering Company Ltd. **Ingot mould production** (*Iron Steel*, 1959, **32,** Jan., 25–26) A description of the new plant for 1–15-t ingot moulds put into operation by the Brightside Foundry & Engineering Co. at Ecclesfield.

The partially mechanized cement sand moulding shop with a rhythmic sequence of operations W. Hoeg (*Giesserei*, 1959, **46,** Feb. 12, 81–86) The organization of a partly-mechanized cement sand moulding shop is described, and its advantages are enumerated.

Cupolas F. Dunn and H. J. Leyshon (*Iron Steel*, 1958, **31,** Dec. 24, 632–636) An account is given of cupola design and operation. The future prospects for the hot blast cupola are considered and aspects meriting further investigation are put forward.–A.G.

This cupola benefits foundries by beneficiating iron ore C. McGlone (*Mod. Castings*, 1958, **34,** Dec., 25) Molten cupola iron is converted to fine iron powder by pouring into a stream of water. The powder is used in a heavy media beneficiation plant at the Minnesota iron mines.—A.G.

Rotary furnaces F. Dunn (*Iron Steel*, 1958, **31,** Dec. 24, 637–638) The design, principle and methods of firing rotary furnaces are described. It is considered that such furnaces will continue to be used for batch melting in the production of malleable irons, as a superheating unit and as a holding furnace in duplex melting processes.—A.G.

Air furnaces K. H. Wright (*Iron Steel*, 1958, **31,** Dec. 24, 639–642) The main features of air furnace design, construction and melting practice, are discussed. The relatively low capital and operating costs will probably ensure the continued use of air furnaces for the production of bulk quantities of metal of controlled quality.—A.G.

The importance of the induction furnace for the foundry K.-H. Brokmeier (*Giesserei*, 1959, **46,** Mar. 12, 129–136) The metallurgy and economics relating to the use of induction crucible melting furnaces in the foundry are discussed.

Operating experience with an 8-t mains-frequency induction crucible furnace H. Rosenberg and W. Dobber (*Giesserei*, 1959, **46,** Mar. 12, 136–137) An account is given of the lining and operation of an 8 metric t induction furnace, with automatic indication of sources of trouble.

Graphite consumption during melting of alloy cast iron in a 300 kg graphite-rod furnace K. Wagner (*Giesserei*, 1959, **46,** Feb. 26, 114–116) The rather expensive graphite rod is destroyed by humidity and oxygen from the atmosphere during melting. The rate of this process is rather slow at the beginning when the graphite rod is smooth but increases rapidly with increasing roughness of the rod. Rod consumption depends not only on the monthly quantity melted down, but also on the number and weight of the melts, i.e. it shows a similar dependence to the current consumption.—T.G.

The thermal and elastic properties of eight cast irons D. Fitzgeorge and J. A. Pope (*Trans. N.E. Coast Inst. Eng. Ship.*, 1959, Preprint, 285–330) Materials for combustion chamber parts for Diesel engines were examined with a view to the use of the Eichelberg 'quality factor'. Even with modifications the expression was found too insensitive for use as a reliable index of quality and further theoretical work on these lines is regarded as unpromising.

Growth and scaling in S.G. iron R. J. Maitland and I. C. H. Hughes (*Iron Steel*, 1958, **31,** Dec., 573–577) The authors studied the effect of Si on the growth and scaling of nodular graphite irons in the range 1·2–5·7% Si at 650–1000°C. Increasing Si content inhibits growth and scaling below the austenite transformation, where both are slow, but above this transformation point they become excessive and it appears from the results that Si then promotes growth and scaling (15 refs.).—T.G.

The subject of an austenitic manganese cast iron with nodular graphite N. Popescu (*Rev. Met.* (*Bucarest*), 1958, **3,** (3), 73–77) The manufacture and properties are described of an austenitic manganese cast iron with a nodular graphite structure produced by inoculation with Mg.

Research on the influence of magnesium on the contraction of cast iron L. Sofroni, R. P. Todorov and G. I. Koshovnik (*Rev. Mét.* (*Bucarest*), 1958, **3,** (3), 61–72) Investigation of the effect of varying amounts of residual Mg in cast iron on contraction of the iron showed that Mg influences contraction characteristics by its effect on the amounts of eutectic and sub-eutectic graphite formed.

Investigations into the use of zinc- and aluminium-containing magnesium alloys compared with pure magnesium in the production of nodular cast iron H. Grossmann (*Giessereitechnik*, 1959, **5,** Feb., 48–52) The effect of Zn on the formation of spheroidal graphite, and of Al introduced together with the Mg on strength, have been studied. Mg alloys containing Zn and Al were found to have no deleterious effect.—L.J.L.

Lanthanum, the rare earth that softens ductile iron A. P. Alexander (*Mod. Castings*, 1958, **34,** Dec., 24) The addition of Mg ferro-silicon plus a mixture of rare-earth metals containing 30% La to molten grey iron is said to yield a ductile graphite iron. This effect demands 0·004–0·02% La, is independent of iron composition and has yet to be completely explained.—A.G.

Putting into practice a new material: The diffused-graphite cast iron J. Pomey (*Microtecnic*, 1959, **13,** Feb., 20–29). The development of this material in which ϵ-hexagonal carbide crystals from tempered martensite are suitably nucleated so as to disperse the graphite formed finely and uniformly is described. Mechanical properties are given and structures are shown, and comparative tests with steel and machining properties were also measured.

Investigation of heat treatments and mechanical properties of high strength steel castings J. W. Tyler and P. J. Ahearn (*US Dept. Commerce, Office of Tech. Services*, PB 131638, 1957, Aug., pp. 23) SAE 4340 steel castings modified with 0·15% V can be heat-treated to a strength level of 280000 psi with a yield stress at 0·1% offset of 200000 psi. High-Si steel with 0·37%C, 1·46%Mn, 1·54%Si, 1·3%Ni and 0·31%Mo, to 290000 and 215000 psi respectively. These were obtained with 2 in. section size and in some cases a Charpy V-notch value of 10 ft/lb at −40°F was obtained.

High-alloy castings: Specifications and properties E. A. Schoefer (*Met. Prog.*, 1958, **74,** Dec., 95–97) The properties and composition of castings made from corrosion- and heat-resistant alloys are often grouped under the name 'stainless steel'. They all contain Fe, Ni and Cr, as main constituents and Mn, Si and C, the effect of all these elements on the alloys is discussed.—T.G.

Corrosion and heat resistant high-alloy castings (*Met. Prog.*, 1958, **74,** Dec., 96B–96C) Metal progress data sheet. Standard designations, chemical composition ranges, mechanical properties, corrosion resistance, typical uses and other information are compiled.

High-alloy castings: Selection of alloys for corrosion-resistant service W. T. Bryan (*Met. Prog.*, 1958, **74,** Dec., 102–105) A guide is given on the correct selection of an alloy for corrosion-resistant service. The corrosive environment should be studied for oxidizing or reducing characteristics, temperature and influence of contaminants. Fe-Cr alloys of various Cr contents and the 18 : 8 stainless steels with and without 2·5%Mo are the main representatives of the iron-base group of these alloys.—T.G.

Pinhole porosity in high-alloy steel castings R. J. Mangone, A. M. Hall, W. T. Bryan, and C. E. Sims (*J. Metals*, 1958, **10,** Dec., 810–814) The mechanism of the formation of pinhole porosity in high-alloy steel green-sand castings is discussed, with reference to the role played by water vapour, hydrogen, oxygen and nitrogen, and the effect of Se additions in alleviating porosity. Moulding and casting techniques to minimize porosity are outlined.

Influences of the granulometric and mineralogical composition of foundry sands on their behaviour in use F. Hofmann. (*Giesserei*, 1959, **46,** Jan. 29, 49–54) Separate fractions of sands of different grain forms were each bonded with 5% bentonite. The influence of grain size, distribution and composition in the properties of mould and core sands were investigated.

Contribution to the measurement of the 'region of trueness to mould' of moulding sands F. Roll (*Giesserei*, 1959, **46,** Jan. 29, 54–60) New testing equipment is described for the experimental determination of the 'trueness to mould' of a moulding sand, and the relation of this property to the gas permeability and strength of the sand.

Wood patternmaking for foundrymen designers, patternmakers (*Mod. Castings*, 1958, **34,** Dec., 29–35) The preparation of wood for patternmaking is described starting from the selection of the tree. Details of new tentative standard colours for painting new patterns are given.–A.G.

'A complete change of programme?' Holroyd & Hall Ltd, adapt a Bradford cinema for patternmaking (*Found. Trade J.*, 1958, **105,** Dec. 11, 715–717) The conversion of the old 'Empress' cinema—a long established landmark in Bradford—into a modern, well-lit patternmaking shop is described and illustrated.—T.G.

Gating for production of high-duty iron castings L. Clarke (*Brit. Found.*, 1958, **51,** Dec., 607–613, discussion, 614–615) Spacing of patterns relative to box type, comfortable pouring and adequate weighting is discussed and bush types, slag traps and chaplets are considered. Design of varying sections is dealt with and also warping and escape of gases. Metal flow, turbulence and metal temperatures are reviewed and the removal of

the running system, grinding and dressing and machining requirements are referred to.

Suitable construction of moulding machine bins G. Bienwald (*Giesserei*, 1959, **46**, Jan. 29, 63–66) Improved design, the use of vibrators and internal coatings to minimise 'scaffolding' in moulding machine bins are described.

Scientific problems in the technique of moulding materials R. Grochalski (*Giesserei*, 1959, **46**, Jan. 29, 60–63) Subjects dealt with include: the physics—chemical significance of bonding power; the practical evaluation of theoretical findings; experiments on sand for the shell moulding process and on moulding sand, and boundary surface problems.

The effect of heat on the properties of compacted moulding materials J. L. Evans and J. White (*Brit. Found.*, 1958, **51**, Dec., 615–625) A study of the factors determining the development of the hot-strength peak in moulding sand mixes and the effect of this peak on the retained strengths on cooling was made. The peak is the point at which increased sintering is offset by liquid formation and softening of the bond with rise of temperature and is a property of the clay used. It develops only at slow rates of heating as appreciable time for sintering is needed. It is not found to be significant in hot tearing. Knock-out properties are partly conditioned by the peak temperature and the use of a more refractory clay with zircon sand is suggested. The hot strengths of CO_2-process sands were found to be virtually zero above 700°C but retained strength was high and organic additions did little to ease breakdown.

Liquid synthetic resin, an economic core binder H. Berndt (*Giesserei*, 1959, **46**, Jan. 29, 66–69) The compositions, properties and mode of application of phenolic core binders, and the use of phenolic pitch as an additive are described, and the advantages of this type of binder are given.

The properties and testing of materials used in the CO_2 process D. A. Taylor (*B.C.I.R.A. J. Res. Dev.*, 1958, **7**, Dec., 401–435) Factors influencing the properties of moulds and cores produced by the CO_2 process have been studied at room and high temperatures. Economies can be obtained by diluting the CO_2 with air or using a proportion of reclaimed sand. The effects of certain inorganic materials on the quartz-cristobalite conversion and the ease of breakdown of cores after casting have been investigated.—A.G.

The effects of mould rigidity, moulding sand properties and pouring temperature on the soundness of unfed grey iron castings K. E. L. Nicholas (*B.I.C.R.A. J. Res. Dev.*, 1958, **7**, Dec., 446–475) The effect of factors influencing casting expansion on the soundness of flake and nodular graphite test castings has been studied, with particular reference to pouring temperature.—A.G.

Experience with experiments on the production of shaped chill castings G. Schwarz and D. Junghans (*Giessereitechnik*, 1953, **5**, Feb., 35–46) The experiments described aimed at extending the range of application of chill casting. Criteria are given for the selection of components suitable for the process. Chill construction for each example is described in detail.—L.J.L.

Manufacture and use of centrifugal cast iron G. Engler (*Giesserei-Techn.*, 1958, **4**, Oct., 250–253). A review of the process with reference to the production of cylinder liners.

On the nature of the expansion of iron castings occurring before contraction V. P. Chernobrovkin (*Fiz. Met. Metallov.*, 1957, **5**, (3), 563–564) The initial expansion occurring when iron is poured into the mould (preshrinkage expansion) is attributed (*a*) to the formation of an austenite-graphite eutectic, (*b*) to thermal expansion of the solidified shell of the casting, and (*c*) to the growth of graphite inclusions in this shell.

Exudations due to mould defects J. Czikel (*Giessereitechnik*, 1959, **5**, Feb., 47) An example is given to show that exudations on castings can occur when the mould gives so that a cavity forms in the skin.—L.J.L.

Study on the fire crack of ingot mould cast iron Y. Maeda (*Tetsu to Hagane*, 1958, **44**, Sept., 1004–1005) The length of the cracks is shown to be a min. at 4·2–4·3% equivalent carbon.—K.E.J.

Practical application of statistical control in a steel foundry (*Mét. Constr. Mécan.*, 1959, **91**, Jan., 19–26) The calculation and construction of quality control charts are described together with their application to the control of steel analysis in a foundry.—A.G.

Air injection and extraction in foundries K. Nilsson and Y. Bovin (*Giesserei*, 1958, **45**, Nov. 6, 689–698) The authors describe modern air injection and extraction plants used in Swedish foundries. Technical details are discussed, in particular the planning of new plants, and costs for installation and running are quoted.—T.G.

New way in the elimination of dust and fumes in the foundry T. Wrene (*Giesserei*, 1958, **45**, Nov. 6, 698–700) The author describes a novel ventilation system in which dust and fumes are extracted from the building through openings in the floor. He lists a number of advantages in favour of this type of ventilation as compared with the conventional one.—T.G.

New working methods in foundries—no accidents H. Lorenz (*Giessereitechnik*, 1959, **5**, Feb., 53–54) Operating experience at the VEB Leichtmetallwerk Rackwitz (Eastern Germany) with the CO_2 method of making cores for moulds is reported.—L.J.L.

VACUUM METALLURGY

Problems of the use of vacua in metallurgy A. M. Samarin (*Primenenie Vakuuma v Metallurgii*, 1958, 3–13) This is an introductory chapter to a collection of papers on vacuum metallurgy. It assesses the extent and importance of vacuum methods in the USSR and briefly reviews important research work and practical trials and applications.

Vacuum melting and heat treating. II. Vacuum heat treating (R. R. Giler (*Ind. Heat.*, 1958, **25**, Aug., 1516–1520, 1522, 1524, 1526, 1670) Metal vapour pressure and degassing processes are considered and furnace design is then reviewed and examples are given.

On the vacuum casting of steel. II. Comparison of vacuum cast steel and air cast steel T. Asakuma (*Tetsu to Hagane*, 1958, **44**, Sept., 1034–1036) Ni-Cr-Mo steels are compared as to H_2 content; the effects of heat treatment, forging and casting conditions on ductility; and ultrasonic testing.—K.E.J.

On the vacuum melting and casting of steel S. Mackawa (*Tetsu to Hagane*, 1958, **44**, Sept., 1036–1037) Comparisons are given between air- and vacuum-melted steels for yields of C, Si, Mn, P and S; gas in the ingots; nonmetallic inclusions and grain size; and Charpy impact value.—K.E.J.

Control of chemical elements and gases in steel in the vacuum melting process T. Tanoue (*Tetsu to Hagane*, 1958, **44**, Sept., 1032–1034).

Study on vacuum melting of pure iron and stainless steel. I. On the crucible ingot structure and recovery of added elements T. Mori (*Tetsu to Hagane*, 1958, **44**, Sept., 1040–1041).

Ball-bearing steel made in a vacuum melting furnace M. Ueno (*Tetsu to Hagane*, 1958, **44**, Sept., 1104–1106).—K.E.J.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Electric furnaces F. S. Leigh (*Iron Steel*, 1958, **31**, Dec. 24, 643–646) Within the three main classes of resistance, induction and arc furnace there are many variations of design which are briefly considered, together with their applications. The relatively stable cost of electricity permits electric furnaces to complete favourably with fuel fired furnaces.

Heat-treatment of metals in resistance furnaces, including resistance melting furnaces A. Grossmayer (*Österreich. Ing. Z.*, 1958, **1**, Sept., 394–400) The merits and superiority of electrically heated furnaces are stressed, in spite of the specific higher energy costs, for the heat-treatment of ferrous alloys. The various processes are treated individually.

Studies on sub-zero treatment of steels. I. Effect of sub-zero treatment on the mechanical properties of some tool steels H. Susukida (*Tetsu to Hagane*, 1958, **44**, Sept., 1091–1093) Details of hardness and wear tests are given.

Continuous heat treatment with automatic control R. O'Donoghue and L. G. W. Palethorpe (*Autom. Prog.*, 1958, **3**, Sept., 326–328; Oct., 371–373) Types of furnace are described and the progress in line hardening is reviewed. Control of progress, heating and quenching is then outlined.

Effect of heating rate in heat treatment. II. Effect of heating rate on the properties of heat treated 13%Cr stainless steel T. Mori (*Tetsu to Hagane*, 1958, **44**, Sept., 1126–1127) With rapid heating, the hardness falls at a higher temp. than with slow, and the minimum is higher. Grain coarsening occurs at a higher temp., but reaches a higher maximum.

III. The effect of heating rate on the heat treatment of steel sheets for galvanizing (1072–1074) Graphs show the effects of slow heating in producing an earlier fall in hardness, tensile strength and grain size, and an earlier rise in elongation with increasing temp.—K.E.J.

High-temperature carburizing: possibility of short-cycle treatment (*Iron Steel*, 1958, **31**, Dec., 596) Steels that can withstand grain growth at high temperatures, e.g. of the order of 1100°C, may be carburized in a very short time. The results obtained by Ipsen Industries Inc. at Rockford, Ill., on a variety of steels, the compositions of which are listed, are presented as graphs. Times of 1–3 h are sufficient for adequate case-hardening.—T.G.

Installation, maintenance and safety considerations for induction and dielectric heating F. T. Chesnut (*Indust. Heat.*, 1958, **25**, Dec., 2418—2428) The safety devices and features —as well as their maintenance and operation— are described for induction and dielectric heating equipment operating at high-frequency and high voltage and often also in a vacuum.

Surface effects occurring during the heating and cooling of plain carbon steels M. J. Olney and G. C. Smith (*JISI*, 1959, **193**, Oct., 107–116) [This issue]

Nitriding and its influence on various heat-resistant alloys C. Vollers (*Metalen*, 1959, **14**, Feb. 14, 41–2) [In Dutch]. It is pointed out that nitrogen is not altogether an inert gas in that it shows a surface reaction with certain metals and alloys exposed to it in molecular form, e.g. hot ammonia gas. Information is given on tests conducted on various alloys in sheet form containing Ni, Cr and Fe placed in the pipe system of an ammonia plant where they were subjected to a temperature of 500°C for 1540 h. Some of the samples were mirror polished and others were pre-treated to impart an extra protective skin of oxide. A table and graph appear in the text which indicate the results of the tests. It seems that the presence of Cr promotes heat resistance and the samples containing in addition a high Ni percentage came out well. An interesting feature was that of stainless steels, two of the samples provided with an extra protective oxide skin showed a much higher resistance to attack by ammonia gas than those that were mirror polished. Pure Ni did not behave particularly satisfactorily.—F.R.H.

Annealing problems of hot rolled mild steel sheets for tin plate I Yano, K. Suzuki, J. Higo, H. Takahashi and S. Tanaka (*Toyo Kohan*, 1952, Nov., 49–55) By heating the middle and lower parts of annealing boxes more strongly, using short flame burners, the temp. distribution in the pile of sheets is improved, the greatest difference being below 20°C. To obtain good Erichsen values, sheets should be annealed at 840°C for 8 h or more.—K.E.J.

Automatic control of continuous annealing (*Autom. Prog.*, 1958, **3**, Dec., 462) A brief account of the Walsall stainless steel mill installation.

How nickel affects high-speed tool steels R. F. Hehemann and A. R. Troiano (*Iron Age*, 1958, **182**, Dec. 25, 52–56) Annealing and hardening conditions for Ni-modified grades are given. Austenite retention, hardening and grain-size reduction can be produced and curves illustrating some of these are given and structures are shown. Conditions for cyclic treatment and repeated tempering are also suggested.

New thermochemical techniques. I. Bright annealing P. Galmiche (*Met. Fiz. J.*, 1959, **5**,

Mar., 113–116) The ONERA Cr-diffusion process is described. Steels and refractory alloys are considered and various uses are briefly noted.

A resistometric study of the first stage of tempering in plain carbon steels H. W. King and S. G. Glover (*JISI*, 1959, **193**, Oct., 123–132) [This issue]

Study on heat-treatments of bearing steel. I. Effect of quenching and tempering temperatures as well as austenitizing time upon hardness and compressive breaking strength T. Yamamoto (*Tetsu to Hagane*, 1958, **44**, Sept., 1107–1109).—K.E.J.

Behaviour of carbides in the quenching process of high-speed steel K. Tsuji (*Tetsu to Hagane*, 1958, **44**, Sept., 1087–1089) The percentages and compositions of carbides and matrices are given for various degrees of quenching.—K.E.J.

The ageing of low-carbon steel sheets containing nitrogen T. Ando (*Tetsu to Hagane*, 1958, **44**, Sept., 1115–1116) Quench-ageing under various conditions and strain-ageing are studied.—K.E.J.

Barrel furnaces boost stainless bar production (*Steel*, 1958, **143**, Dec. 26, 64–66) A heat treatment unit is described consisting of 5 barrel-type heating furnaces and a quenching ring. It occupies less space than conventional equipment and offers other advantages which are discussed.—A.G.

Thermal considerations in oil quenching G. Stolz jun., V. Paschkis, C. F. Bonilla, and G. Acevedo (*JISI*, 1959, **193**, Oct., 116–122) [This issue]

Tempering type 410 stainless steel C. F. Lewis (*Met. Prog.*, 1958, **74**, Nov., 88–89) By adapting the Holloman-Jaffe tempering parameter, simple charts, usable by shop personnel, have been devised for specifying the tempering treatment of Type 410 stainless steel to obtain the desired hardness.—D.L.C.P.

Study of a matrix austenite at room temperature, and its decomposition on tempering, carried out in the steel Z180 C13. Part I A. Faure (*Mét. Corros. Ind.*, 1959, **34**, Feb., 72–80) Specimens of Z180 C13 steel (Type 1·8%C, 13%Cr) were heated at various temperatures from 1000–1200°C, held for various times at these temperatures, cooled in air, and the structure and properties examined. It was shown that a completely austenitic matrix at room temperature is obtained by holding at 1175°C for 6 min. The characteristics of the steel and the experimental conditions are described.

Residual stresses in solid rolled wheels due to various kinds of heat treatments N. Oda and K. Nishioka (*Sumi. Met.*, 1958, **10**, July, 137–143) Normalizing, forced air chilling, normalizing and tempering, forced air chill and tempering, rim-quenching and tempering and tempering alone were examined. No significant difference in circumferential stresses were found, the stresses were all compressive with a maximum value of 20 kg/mm in the normalized-and-tempered wheels. In the wheel disc the untempered wheels had stresses of opposite sign in the inner and outer faces and a residual tensile stress of 20–30 kg/mm² appeared on the inner face near the boss. After tempering stresses were small and mainly compressive.

FORGING, STAMPING, DRAWING AND PRESSING

Light forge opened at Walter Somers Ltd (*Brit. Steel.*, 1958, **24**, Dec., 400–402) An illustrated account.

Effect of forging on the transformation characteristics of large alloy steel products S. Onodera (*Tetsu to Hagane*, 1958, **44**, Sept., 1122–1123) The structures at various positions in rotor shafts and as-cast and as-forged ingots are examined.—K.E.J.

Theoretical analysis of bloom and billet forging J. G. Wistreich and A. Shutt (*JISI*, 1959, **193**, Oct., 163–175) [This issue]

Spread and elongation in flat tool forging A. Tomlinson and J. D. Stringer (*JISI*, 1959, **193**, Oct., 157–162) [This issue]

Reduce manual handling to boost forging output H. Chase (*Iron Age*, 1958, **182**, Dec. 18, 102–103) The advantages of mechanizing and synchronizing the various stages in a forging operation are discussed with reference to the production of a forged blank for a differential side gear.—A.G.

Vibrations and their incidence in relation to the foundations of machinery and their installation M. C. Paillet (*Mém. Soc. Ing. Civils France*, 1958, **11**, (6), 441–450) Examples are discussed under three headings: violently-moving machines (power hammer and vibrating screen); static machines (grinder), and high-output rotating machines.

Forming of forks and spoons and similar parts made of brass, nickel-silver, and chromium-nickel steel in hydraulic, toggle, and screw presses and drop hammers E. F. Scheven (*Z. Metallkunde*, 1959, **50**, Feb., 106–112) The forces required for forming forks, spoons and the like were measured electrically in order to find the best forming method and to reduce failures of the dies, which showed large differences in service life. The shape of the deformation/forming-force curves is, for the three metals studied (the steel was an 18 : 8 steel) very similar, and shows that the toggle press gives at equal power the largest deformation and the drop-hammer the least. The results are presented in graphs.—T.G.

Trouble-shooting in the press room: Blanking of large pieces F. Strasser (*Iron Steel*, 1958, **31**, Dec., 579–581) In view of the high costs of the tools, their very short life (as compared with dies for small pieces), and the difficulties involved in the blanking of large pieces the author advises the use of other means of production wherever possible and makes recommendations. For the case where none of these other methods of avoiding blanking dies can be used, the author makes a number of recommendations for overcoming these difficulties.—T.G.

Experimental investigation of pump drive without accumulators for hydraulic presses A. I. Zimin (**From German translation of Russian book*, 130–141) A study of a 3000-t press powered by rotary pumps was made and measurements were made with devices, and using the circuits, described to calculate power consumption and the dynamic properties of the press throughout the working cycle. A load cell for use in the oil pressure system, and a single-phase loop power consumption meter as well as an inertialess stroke recorder are described.

Improving the punchability of silicon steel C. S. Wukusick and R. S. Zeno (*Tool. Engineer*, 1958, **41**, Dec., 63–70; from *Eng. Dig.*, 1959, **20**, Jan., 35–37) Grain-oriented 3·25%Si steel was examined and three common die materials were used. WC dies are recommended and punchability is improved by prevention or removal of scale. A solid lubricant is also advantageous.

The effective utilization of strip R. M. Evans (*Sheet Metal Ind.*, 1958, **35**, Dec., 911–913, 916) The tooling for stampings from strip with particular reference to the amount and possible re-use of waste is discussed. Strip is used when large quantities of relatively small parts, such as for typewriters, are manufactured.

Minimizing waste in strip cutting G. G. O'Brien (*A.S.M.E. Paper No.58–SA–72*, 1958, pp. 4) A linear programming study. The actual example refers to paper in rolls.

In the variation of tension in stretch-forming a metal strip D. M. Woo (*J. Appl. Mech.*, 1958, **25**, Dec., 623–625) A note. By extending Swift's analysis, the author derives an expression for the tension transmitted along the strip length in contact with the die by taking into account the additional effect of the strain-hardening rate of the metal and the die radius.—T.G.

Steel sheet for deep drawing: Some aspects of its production A. Snedden (*J. Australian Inst. Met.*, 1958, **3**, Nov., 242–249) A review on the requirements and production of deep drawing sheet from rimming and Al-killed steel. The importance of metallurgical controls during fabrication of the sheet is stressed.

Spring wire gets a lift (*Steel*, 1958, **143**, Dec. 1, 70–71) The technique and advantages of the 'cross extrusion' method of making spring wire are described. With this technique the wire leaves the die at 90° to the direction of the applied force. The additional breakup of the normal directional flawlines improves mechanical properties. The method has been used on a variety of metals but refinements are necessary before it can be generally adopted. Cost limits uses of the material to crucial applications where the high quality is valuable.—D.L.C.P.

Hot extruded ductile cast iron E. B. Blake and S. V. Arnold (*US Dept. Commerce, Office of Techn. Services, PB131690*, pp. 20) Ductile irons one inoculated with Ni-Mg and the other with Fe–Si–Mg alloy were cast in 7 in. dia. × 10 in. billets and extruded into 1·10 in., 1·56 in. and 2·21 in. dia. rounds and 2·37 in. outside and 2 in. inside dia. tubes at ~1800°F with glass lubrication and mechanical properties were measured as-extruded, annealed, and quenched and tempered. Behaviour was irregular. The sound extrusion had high strength but negligible ductility. Annealing at 1700°F and slow cooling or quenching from 1700°F and tempering at 1050°F or 1150°F gave excellent combinations of strength and ductility. Impact strength was very low.

On hot-extruded steels manufactured by the Ugine-Séjournet process. I. On the properties of hot-extruded bars of medium carbon and Cr-Mo steels T. Kaneda (*Tetsu to Hagane*, 1958, **44**, Sept., 1002–1004) The results include mechanical properties, hardness, Charpy impact value, fatigue properties and transition temp. curves.—K.E.J.

Operational research studies in the forging industry R. H. Collcutt, J. Banbury, and J. V. Chelsom (*JISI*, 1959, **193**, Oct., 148–157) [This issue]

ROLLING MILL PRACTICE

Experimental studies on the hot working of steel. I. On deformation of rolling material in the roll pass assuming that the roll stand is a rigid body T. Harada (*Tetsu to Hagane*, 1958, **44**, Sept., 995–997) The characteristic deformation curve is determined, and the effect of rolling temp. and rolling speed on spread are investigated.—K.E.J.

Effect of the number of passes on the spread and elongation of billets in hot rolling K. Tihara (*Tetsu to Hagane*, 1958, **44**, Sept., 994–995) Results are given for billets of thickness 25, 35 and 45 mm, at 800°C.—K.E.J.

Comparisons of calculated and experimental values of rolling load T. Okamoto (*Tetsu to Hagane*, 1958, **44**, Sept., 1000–1002).—K.E.J.

Sling speeds roll changes (*Steel*, 1958, **143**, Dec. 26, 67) A simple sling of heavy canvas reinforced with webbing has been used to facilitate roll changes on a large grinder using coated abrasive belts.—A.G.

Roller leveller adds precision to mill production (*Iron Age*, 1958, **182**, Dec. 4, 130–131) The Weirton Steel Co. installation is described.

New universal slabbing mill at Abbey works (*Iron Coal Trades Rev.*, 1958, **177**, Dec. 12, 1407–1409) Planning, layout and construction of a universal slabbing mill with a capacity of 50000–60000 t per week which replaces an existing mill is reported. The main difference between the new mill and other universal mills is that the drive to the vertical roll is through a gear box of unique pattern. The changeover from the old to the new mill is described.—T.G.

Bar mill extensions at Le Creusot (*Engineer*, 1958, **206**, Dec. 26, 1018) A brief account with plan.

Two-in-one pass ups bar yield (*Iron Age*, 1958, **182**, Dec. 4, 132) In the plant described the output of reinforcing bars has been increased 60% by 'double gating', i.e. passing two bars simultaneously through the last five stands.—D.L.C.P.

Water recirculation in steelworks I. M. E. Aitken, E. L. Streatfield and H. C. White (*Institution of Water Engineers J.*, 1959, *preprint*, pp. 32) Designs for water economy in steelworks are discussed. The Park Gate 11 in. continuous bar mill installation is described in detail. The sludge blanket softening process and chemical treatments used are described. Operation data are given and sludge disposal is discussed. An appendix deals with pH control.

Pointing of rod steel by milling or hot rolling? F. Kottmeier (*Stahl Eisen*, 1959, **79**,

Mar. 19, 332–337) Comparison was made between pointing of rods by milling and by hot rolling. The tests were carried out in four works. It was found that milling is a very much cheaper process than hot rolling. A number of interesting points were raised in the discussion.—T.G.

Hot rolling with the planetary mill C. J. Baker (*Sheet Metal Ind.*, 1958, **35,** Dec., 939–951) A review and discussion of a planetary hot mill including a detailed description of the stand and the roll assembly, the theory of working, results of model tests and mode of operation of the plant. Economics of the process are mentioned.—T.G.

The Brinsworth medium hot-strip mill of Steel, Peech and Tozer (*Sheet Met. Ind.*, 1959, **36,** Feb., 101–115; *Metallurgia*, 1959, **59,** Jan., 3–9) Illustrated accounts of the new mill are presented **New Brinsworth mill** (*Iron Steel*, 1959, **32,** Jan., 13–17) The layout and operation are described of the new Steel, Peech and Tozer Brinsworth continuous strip plant **Brinsworth strip mill** (*Brit. Steel*, 1959, **25,** Jan., 14–17) An illustrated account of the equipment and performance of Steel, Peech and Tozer's new continuous hot strip mill at Brinsworth **The Brinsworth hot-strip mill** (*Engineer*, 1958, **206,** Dec. 19, 971–973).

The continuous wide strip mill at the Thyssen works, Duisburg (*Mét. Constr. Mécan.*, 1959, **91,** Jan., 11–16). A description is given of the Thyssen mill which includes an automatically controlled cold strip mill currently producing 20000 t a month.—A.G.

Experimental report on the relations between skin pass working conditions and skin pass elongation of tin plate base metal H. Matsunaga, S. Oki, R. Iwamoto and A. Tada (*Toyo Kohan*, 1954, **3,** Dec., 16–31) Detailed results are given; they show values of the following variables which are effective in elongating the base metal: skin pass mill speed, front tension, working pressure on mill post, back tension, and thickness of plate.—K.E.J.

Deductions from experimental rolling in a four-stand broad-strip cold-rolling mill H. G. Müller and W. Lueg (*Stahl Eisen*, 1959, **79,** March 19, 325–331) The authors studied the effects of factors that lead to thickness fluctuations at the very high speed at which broad strip is cold-rolled. Certain thickness fluctuations of the starting material cannot be eliminated, whereas others can. The various factors involved and the requirements on the control units are described in detail.—T.G.

The Pilger-step cold-rolling of tubes and its application as compared with cold-drawing O. Pawelski (*Stahl Eisen*, 1959, **79,** Mar. 19, 365–366) A brief historical review and an appraisal of the Pilger step-process are given. The author outlines the field of application of the Pilger process as opposed to drawing, and indicates the superiority of this rather new process.—T.G.

A study on reduction and solid phase welding of ingot pipes by hot rolling T. Oda (*Tetsu to Hagane*, 1958, **44,** Sept., 987–988) Curves show the draft required to reduce and to close pipes of dia. up to 25 mm in small ingots. Results are given for tensile strength, for varying degrees of bonding.—K.E.J.

Power for hot-strip rolling (*Elect. Times*, 1958, **134,** Dec. 25, 973–974) The new Brinsworth mill drives are described **Electrical drives for the new Brinsworth 16 in. hot-strip mill of Steel, Peech and Tozer** M. H. Jahn (*English Electric J.*, 1958, **14,** Dec., 3–22) **Steel strip production** (*Elect. Rev.*, 1958, **163,** Dec. 26, 1187–1190) A review of the drives and electrical equipment of the Brinsworth mill.

Drive and control system for high-speed rod mill (*Iron Steel*, 1958, **31,** Dec., 585–588) The electric drive and electronic control systems of the combination rod mill—consisting of 25 roll stands and having an annual capacity of 450000 t—at the Cuyahoga works of the United States Steel Corporation of Cleveland are described.—T.G.

Planning the electric drives for a tandem cold-strip mill H. J. Marx (*Stahl Eisen*, 1959, **79,** Mar. 19, 362–365) The author reviews the various methods recommended for the selection and calculation of the drives of cold-strip tandem mills.—T.G.

On the thickness control of hot-rolled tinplate by quality control charts S. Kunishige and K. Saeki (*Toyo Kohan*, 1952, Nov., 56–60) By deciding standards for the weight of tin bar, amount of scrap in rolling, and length of finished pack, and standard deviations, the best mean value and minimum variation of the thickness of pack-rolled sheets can be determined from a statistical equation.

Automatic gauge control is applied on new high-speed tandem tinplate mill A. F. Kenyon (*Iron Steel Eng.*, 1958, **35,** Dec., 148) A description of the gauge control system at the tinplate mill at the Ohio plant of Wheeling steel.

Case histories on statistical methods for quality control (regression and correlation) (*A.I.S.I. Contrib. Met. Steel*, 1958, Jan., pp. 76) The subjects reported on are: causes of increased rejects or steel bars produced on a rolling mill, comparison of crew performance on a bar mill, test for effectiveness of a new hot topping practice in the production of killed steel ingots, speed of travel for various wall thicknesses of welded steel pipe, hanging times of blast furnaces with the same burden materials, ability of testing machines to rank deep-drawing properties of steel grades, comparison of two rank correlations for assessment of steel ingot and slab surfaces, OH data, size of heat and tap-to-tap times, defect in coils of Al foil.

Investigation of the surface defects observed after annealing of cold rolled strip steel, especially on the cause of white edged plate Y. Kitamura (*Toyo Kohan*, 1952, Nov., 18–27) The defects which lead to imperfect tinning, viz. carbon edge, white edge and stain, are discussed. Tests show that white edge is merely a surface roughening. When the composition of the annealing gas is far removed from the equilibrium of water gas and producer gas, the strip surface is etched and carbon deposition may occur.—K.E.J.

On β-ray continuous thickness gauging of steel strip K. Takemoto and T. Fujii (*Toyo Kohan*, 1954, **3,** Dec., 38–41) In a gauge of the ionization-chamber type, a compensating cover disc having a centre hole under the window of the chamber reduces the effect of variation of the gauge-specimen distance to $\pm 1\%$ per ± 5 mm. The gauge is thus suitable for continuous measurement of running steel strip.—K.E.J.

Study of the flying micrometer T. Kinto and K. Ito (*Toyo Kohan*, 1952, Nov., 61–65) The accuracy of the flying micrometer for measuring the thickness of cold-rolled coils is improved by using a temperature compensator and by other means.—K.E.J.

On a pinhole detector K. Takemoto and Y. Yamamoto (*Toyo Kohan*, 1954, **3,** Dec., 32–37) A detector for small pinholes in running steel strip, used before the flying shear line, contains a mercury lamp, cylindrical lens and photomultipliers. A detected defective plate is automatically marked and rejected.—K.E.J.

Scale formation on hot-rolled sheet A. Lüth (*Arch. Eisenhütt.*, 1959, **30,** Feb., 71–78) A new method of investigation has been developed in which the scale is detached with HBr filtered, and chemically analysed. Ceric sulphate is used as oxidizing agent and o-phenanthroline as indicator in titration.

Internal defects of semi-killed steel plates H. Gondo (*Tetsu to Hagane*, 1958, **44,** Sept., 983–985) The effects of order of pouring of ingots, larger cropping after blooming, pouring speed and pouring temp. on the depth of defects are investigated.—K.E.J.

Determining the average rate of reduction in rolling along the length (longitudinal rolling) with calculation of the effect of spread E. F. Sharapin (*Stal'*, 1958, *Rolling and tube production supplement*, 31–40) U_x, the rate of reduction is defined as the ratio of the change of height of the compressed object to its height h_x at the given moment, or is obtained from the formula $U_x = \frac{2v_{yo}}{h_x}$, where v_y is the vertical component of the rate of motion of the contact surface of the part of the rolled object which is in the zone of the focus of deformation. A theoretical analysis is given and results from calculations are compared with experimental data.—L. H.

Longer life of sleeves of backing-up rolls for cold-rolling mills M. M. Kobrin and K. V. Shishokina (*Metallov. Obra. Met.*, 1958, (5), 43–48) Besides spalling and fatigue fracture, brittle fracture may occur along a generating line of a shrink-fitted sleeve. These sleeves are up to 200 cm long with outside and inside diameters of 1600 and 800 mm respectively and are made of 9Kh steel with 0·85%C and 1·5%Cr, tempered at 400°C to 60–75 units Shore hardness. Delayed fracture has been studied on notched specimens by holding them for up to 240 h (some for 1800 h) and measuring ordinary tensile strength for those failing to break under this treatment. Specimens exhibiting brittleness showed delayed fracture. Surface hardening is suggested as a treatment for the sleeves unless suitable heat treatment conditions can be found which retains ductility with high hardness and wear-resistance.

A new billet assembly technique for continuous billet mills E. J. Buckman (*BHP Techn. Bull.*, 1958, **2,** Oct., 7–9) A technique has been developed for handling billets at the BHP Newcastle works, using an existing assembly table, which permits faster rolling rates from a continuous billet mill.

Rebar output up 60% with 'double gating' at Oregon steel mill H. E. Jackson (*Western Metalw.*, 1958, **16,** Nov., 55–56) A method of rolling two bars simultaneously has raised the output of $\frac{1}{2}$-in to $\frac{3}{8}$-in. reinforcing bars from 240 to 400 t/h. The process is briefly described.

The grooving of angles by the method of corresponding strips V. S. Smirnov, N. N. Pavlov, and A. Ya. Mochalov (*Stal'*, 1958, *Rolling and tube production supplement*, 147–167) This method was worked out in 1950 (V. S. Smirnov, K. N. Bogoyavlenskii, and N. N. Pavlov – Grooving of rolls by the method of corresponding strips. *Metallurgizdat*, 1953): The method consists (a) in taking the linear measurements and the area of the cross-section of the clean finished section in hot condition, and (b) in converting them into the so-called corresponding strip of a rectangular cross-section. The strip of grooved cross-section, and the rectangular strip are said to be corresponding if their cross-sectional areas and corresponding sides of the cross-section are equal. Calculations with examples are given.

Mechanized edging of rails V. V. Trofimov (*Metallurg*, 1958, (8), 29–31) Edging of light 12·5 m long rails by hand was a possibility, but inconvenient, but edging of heavy 25 m long rails by machinery became a necessity. Edging at the Azovstal' works has to be carried out at five points, and this requires three different designs of edging manipulators which are described and illustrated.—M. T.

Results of rolling trials on a plate mill equipped with twin drive O. Emicke and K.-H. Lucas (*Neue Hütte*, 1959, **4,** Feb., 85–93) Experimental work carried out with a plate mill with a twin drive is described, which provided data for the calculation of roll pressure and torque. It was shown that the practical results obtained with a variety of stock, were proportional to those derived by the use of the Ekelund equation.

Recent development in sheet manufacture and some problems in connexion therewith S. Fujiki (*Tetsu to Hagane*, 1958, **44,** July, 795–799) A review is made of recent installations of hot and cold strip mills in various parts of the world, and of their operating problems. Comparisons are made between various processes of continuous electrolytic tinning; and the Ferrostan process is reviewed in detail.—K. E. J

The hot rolling of thick steel plates clad on one side with stainless steel M. Žídek and B. Glatz (*Hutn. Listy*, 1958, **13,** (8), 679–687) To meet the increasing demands of the chemical industry, clad plates must be produced in greater quantities. Compound ingots are cast in square moulds with stainless steel inserts placed against one wall of the mould. The compound ingots are rolled into slabs in the blooming mill, from which clad sheets of the required dimensions are rolled by dressing the surface. The process requires special heat treatment to obtain the necessary mechanical and

physical properties of the materials, and to produce satisfactory pressure welding of the abutting surfaces where diffusion occurs. A thorough investigation was made of rolling temperatures and pressures of the compound material, and the calculation of the rolling pressures of the compound materials from those of the two components is outlined. All stages of the process are described in detail, as well as control of dimensional tolerances, and calculation of the degrees of reduction of the components of the compound products. The relationship of the last to the thickness of the material and to soaking temperatures was established. Finally a method of calculation was evolved for the optimum sizes of the slabs of stainless steel for inclusion in the compound ingot, and of the compound slabs, in order to obtain the maximum utilization of the plating material.—M. T.

Heavy armour plate for ships requires special processing (*Ind. Heat.*, 1958, **25,** Nov., 2269) In the process described a 111-t ingot 45 in. thick is reduced to 21 in. by forging in a 10 000-t press. The plate is then rolled in a 160 in. plate mill and annealed. The combined forging and rolling is said to yield a high quality product.—A. G.

The twisting operation in a continuous billet mill M. Ya. Brovman and R. M. Shpigel'man (*Stal'*, 1958, *Rolling and tube production supplement*, 137–146) The twisting of strip through 90 or 45° after each stand is effected either by helicoidal twist guides or by roller twist guides. Experiments are described which have been undertaken for a theoretical analysis of the twisting, from the point of view of the permissible angle of twist and of the supplementary expenditure of power for twisting the strip.—L. H.

Experience in rolling with minus tolerance S. V. Gubert, B. V. Merekin, and G. D. Feigin (*Stal'*, 1959, (1), 54–58) Rolling with minus tolerances has just been put into effect at the Nizhne-Tagil plant, adopting a system based on theoretical weights of the finished rolled product in relation to selling prices. It is considered necessary to introduce a bonus system in order to increase metal yield.—R. S.

New rolling mills in the USSR A. I. Tselikov, E. S. Rokotyan, and E. R. Shor (*Metallurg*, 1959, (2), 21–25) Continuous wide strip mills are planned. A mill for sheet 1·5 to 8–10 mm thick appears to be most suitable for costs per t tapped. The best roll barrel length is 1700–2100 mm and output would be 250 t/h or $3{\cdot}5 \times 10^6$ t/year. The weight of equipment would be ~ 18 000 t rolling 15·5 t slabs at up to 15 m/sec, these exceed the parameters of existing mills. New tube mills and a planetary mill are also outlined and details are given of a 20-roll stand for strip, a bar rolling mill and a 3-roll stand for crankshafts and axles.—R. S.

Effect of rolling ratio on distribution of sand marks of bearing steel. The study of non-metallic inclusions.—I M. Kawai and H. Kimura (*Tetsu to Hagane*, 1958, **44,** June, 656–660) The main source of sand marks is from non-metallic inclusions in the ingot. In high-C low-Cr bearing steel rods, the number of small (0·1–0·4 mm) sand marks does not vary with position in the ingot. The number of larger marks is higher at the top of the ingot. With increased rolling ratio, the number of larger marks increases and of smaller marks decreases; at ratios of the order of 250, sand marks disappear.—K. E. J.

Elastic deformation of rolls in cold rolling M. Ya. Brovman (*Stal'*, 1958, *Rolling and tube production supplement*, 168–175) The elastic deformation distorts and increases the angle of bite. A method of calculating this distortion is explained. From experimental findings, it can be deduced that with an increase in the specific pressure on the rolls the increase in the angle of bite is smaller, for example: for an average specific pressure of 87 kg/mm² the increase of the length of arc is 5·4/4·3 mm and for a pressure of 62 kg/mm², 5·5/4·8 mm.

An analysis of the trend of development of rolled tubes in Poland W. Dobrucki (*Hutnik*, 1958, **25,** (6), 195–201) Having made 'An Analysis of the World Movement towards the Development of the Rolling of Tubes with Seams' ((4–5), 156–164), the author now analyses the present production picture in Poland, indicates shortages, development requirements and production targets.—M. T.

Welding of heavy electric motors of rolling mills during repairs N. S. Bazhanov (*Svarochnoe Proizvodstvo*, 1958, (10), 35–37) Cracks in commutators and armatures should be welded up as soon as apparent. Such repair welding requires very skilled operators, but much repair work can be carried out without stripping down motors. The article is devoted to practical methods of making satisfactory repair welds without dismantling.—M. T.

Rebuilding a roller straightening machine M. A. Tylkin and B. B. Ososok (*Stal'*, 1959, (1), 73–74) Reconstruction of a machine with a 4 ft distance between rolls and used for cold straightening of 70 lb and 110 lb per yard rails and also for piling section is described.—R. S.

Investigation of the variation in the dimensions and mechanical properties of grooved steels in the straightening on the roller straightening machine M. P. Yarantsev (*Stal'*, 1958, *Rolling and tube production supplement*, 378–384) Experimental data obtained from the straightening of bars of low-carbon steel, on the roller straightening machine have shown that when the degree of straightening is relatively small, no change in dimensions is noticed as a rule, for example in bars grooved from 12 mm blanks to 10 mm final measurements. Hardness, breaking strength, relative elongation and relative reduction of area are given before and after straightening.—L. H.

An accurate method of calculating [the torque and bending moment] of straightening machines [for rolling mills] A. A. Korolev (*Vestnik Mashin.*, 1958, **38,** (10), 23–30) A thorough exposition of the theoretical basis for the accurate calculation of the torque and bending moment on multi-roller straightening machines is given.—M. T.

LUBRICATION

Lubrication practice in German steelworks H. P. Jost (*Iron Coal Trades Rev.*, 1958, **177,** Dec. 5, 1347–1351) A report of a visit by British engineers.

Conference on lubrication and wear (*Institution of Mechanical Engineers, London*, 1957, pp. 911) **Definitions, symbols and units** (1–5) **A review of hydrodynamic lubrication with particular reference to the conference papers** D. G. Christopherson (9–15) **Experiments on the flow in rotating annular clearances** J. A. Cole (16–19) **High-speed highly loaded bearings and their development** T. W. F. Brown and A. D. Newman (20–27) Bearings for marine turbines are considered **Energy and Reynolds considerations in thrust-bearing analysis** B. Sternlicht (28–38) **Finite gas-lubricated journal bearing** J. S. Ausman (39–45) **Effect of wettability of a lubricant on journal bearing performance** W. E. Campbell, K. Pilarczyk, and C. A. Papp (46–52) **Surface deformations in the hydrodynamic slider-bearing problem and their effect on the pressure development** F. Osterle and E. Saibel (53–57) **Stepped thrust bearings** C. F. Kettleborough (61–63) **A theory of rheodynamic lubrication for a Maxwell liquid** A. A. Milne (66–71) **Re-examination of the stepped thrust bearing** P. B. Neal (72–81) **Predicting sleeve-bearing performance** D. F. Wilcock (82–92) **Investigation of cavitation in lubricating films supporting small loads** D. Dowson (93–99) **Dynamically loaded journal bearings of finite length** H. W. Hahn (100–110) **An Experimental investigation of temperature effects in journal bearings** J. A. Cole (111–117) **A method of designing plain journal bearings for steady loads** A. E. Burke and M. J. Neale (118–122) **High-speed journal bearings** M. J. Neale and P. P. Love (123–127) Gas turbines and turbo-blowers are considered. A special test head and gearbox for testing is described. **An experimental comparison between three types of heavy duty thrust bearing** D. de Guerin and L. F. Hall (128–134) Loads up to 100 t at speeds of up to 3000 rpm were considered. **Temperature distribution within lubricating films between parallel bearing surfaces and its effect on the pressures developed** O. C. Zienkiewicz (135–141) **Some characteristics of conventional tilting-pad thrust bearings** D. de Guerin and L. F. Hall (142–146) **Visual study of film extent in dynamically loaded complete journal bearings** J. A. Cole and C. J. Hughes (147–150) Glass bushes in ultra-violet radiation were used. **Mechanism of lubrication in porous metal bearings** V. T. Morgan and A. Cameron (157–157) **Experimental investigation of power loss in high-speed plain thrust bearings** J. A. Cole (158–165) **Observations on the performance of air-lubricated bearings** J. A. Cole and J. Kerr (164–170) **On grease lubrication of a slider bearing** A. A. Milne (173–175) **New fundamental testing methods applied to lubricants; measurement of mechanical properties in continuous flow** A. Jobling and J. E. Roberts (176–178) **Journal bearing instability** B. L. Newkirk (179–185) This is a review of investigations of the disturbances observed in the rotors of blast-furnace compressors with operating speeds more than twice the critical speeds. Rotor flexibility is considered and special bearing designs giving safer operation can be made use of. With stiffer rotors, instability sets in at lower relative speeds (as calculated from shaft stiffness alone) and criteria for instability and procedures for calculating oil film elasticity are proposed. In an addendum later papers are included in the review. **Film extent and whirl in complete journal bearings** J. A. Cole (186–190) **Vibrations in journal bearings: Preliminary observations** A. Cameron and P. J. B. Solomon (161–197) **Marginal and partial hydrodynamic lubrication with particular reference to the conference papers** H. Blok (198–204) The subjects particularly reviewed are: the initial geometry of the rubbing surfaces in their unloaded state; micro-geometry (or roughness) is included; the reversible changes in geometry occurring in service by elastic deformation and the irreversible ones by running-in and wear; and the response of lubricants to the conditions to which they are subjected is the lubricating film. **Some scuffing experiments in a disc machine** A. W. Crook and B. A. Shotter (205–209) En28, En26 V12, En30B and a 0·3%C and a 0·4%C steels were tested (analyses and hardnesses given) to investigate an unusual form of wear in gears of En28, using a turbine oil whose properties are given. The results with various pairs of these steels are tabulated and discussed. The detritus formed is briefly described and the mechanism of scuffing is discussed and it is concluded that it is a function of the materials and the surface finish and independent of the hydrodynamic film behaviour. The wear conditions of the gear were reproduced and shown to be pitting of surfaces already strained by scuffing. An effect of surface temperatures was demonstrated. **A study of bearings under failure conditions** T. W. F. Brown and A. D. Newman (210–213) A new bearing design was evolved from these tests for marine turbines. **The viscosity-pressure dependence of some organic liquids** J. W. M. Boelhouwer and L. H. Toneman (214–218) **The foil bearing** B. J. Patel and A. Cameron (219–223) **The importance of surface finish, loaded area conformity and operating temperature in small end plain bearings for high duty two stroke engines** E. A. Blount and D. de Guerin (224–229) **A review of boundary lubrication with particular reference to the conference papers** C. B. Davies (319–325) **The importance of oil-metal adhesion in lubrication** E. J. Clayfield, J. B. Matthews, and T. V. Whittam (326–332) Spreading pressures of oils on stainless steel were measured and the effects of mixing and heating the oils were also observed. Additives influence spreading pressure. It is not clear whether it is spreading pressure or work of adhesion that prevents contact in sliding. **Investigation of boundary lubrication in kinetic friction by means of a wire tribometer** V. P. Lazarev and B. V. Derjaguin (341–347) A device using a long contact region is described and results with various lubricants are given. **On the influence of grease structure on boundary lubrication** A. A. Milne and W. L. Cooke (355–358) **The lubrication of fluid seals** D. F. Denny (392–395) **Study of design criteria for porous metal bearings** V. T. Morgan (405–408) **A review of the papers on the lubrication of rolling bearings and gears** L. F. Hall (425–429) **Recent advances in grease lubrication of ball bearings** E. R. Booser (430–437) **Current development problems in high temperature aircraft roller bearings** C. C.

Moore and P. Lewis (438–443) Vacuum-melted steel with 1% Al was the material used. **Observations on the movement and structure of grease in roller-bearings** A. A. Milne, D. Scott, and H. M. Scott (450–453) A transparent model was used. **Influence of load and motion on the lubrication and wear of rolling bearings** A. Palmgren and B. Snare (454–458) **Testing of marine main-propulsion-gear lubricants in disc machines** H. J. Watson (469–476) Tests on twenty-one steels with various hardnesses and heat-treatments simulating operating conditions were carried out. **A review of the papers on IC engine lubrication. Miscellaneous lubricants and applications and additives** J. G. Withers (493–497) **Lubrication in wire drawing** J. G. Wistreich (505–511) The physical aspects are examined in the light of recent research. **Flow properties of lubricating grease** D. Summers-Smith (519–523) Viscometers are compared and correlated with grease properties. **Sulphur as an extreme pressure lubricant** R. B. Campbell (534–538) PbS was studied using a tracer technique. **The Shell four-ball EP lubricant tester: Methods of use and precision in the determination of the EP properties of lubricants** J. R. Hughes (575–582).

WELDING AND FLAME CUTTING

Welding research in the United Kingdom A. A. Wells and P. T. Houldcroft (*Canad. Metalw.*, 1958, **21,** June, 62–66) The organization of the British Welding Research Association is briefly described and its major research work outlined.—T. G.

Casting and welding M. Skralovnik (*Varilna Tekhn.*, 1958, **7,** (1–2), 14–19) [In Serbocroat] The advantages derivable from the complementary joint use of casting and welding are discussed.—P. F.

Determination of arc-welding costs—I. H. Thomasson and S. Kerr (*Canad. Metalw.*, 1958, **21,** Dec., 42–46) The basic factors for an assessment of arc-welding costs are discussed.

Diffusion welding *in vacuo* N. F. Kazakov (*Avtom. Svarka*, 1958, (8), 6–18) A special device is described in which welding *in vacuo* up to 1300° *c* can be carried out. The effect of pressure, temperature, purity of the surface, composition and the properties of metals and alloys on weldability were investigated. The findings show that the strength of the metal–ceramic weld to the metal base depends on the cobalt content in solid solution and on the grain size. An increase in pressure has little effect on welds at low temperature but at elevated temperatures the influence is considerable. However pressures above 2·5 kg/mm^2 have no effect on the quality of the weld.

On pre-heating temperatures in welding heat-resisting steels K. Mrosko (*Zvár. Sbornik*, 1958, **7,** (1), 42–51) [In Slovak] By means of hardness measurements on welds in mild and low-alloy steel sections of 1–5 cm thickness, welded in a specially designed machine by a standardized method, the optimum pre-heating temperatures were determined. These depend upon the carbon equivalent, the dimensions of the bars and upon the electrode diameter.—P. F.

Shielded arc welding under carbon dioxide D. Uran (*Varilna Tekhn.*, 1958, **7,** (1–2), 10–14) [In Serbocroat] Economic and technical aspects of CO_2-welding are discussed in the light of recent publications.—P.F.

Electric slag welding of 20GS steel V. M. Semenov (*Svarochnoe Proizvodstvo*, 1958, (10), 21–23) Results are given of experimental electric slag welding of two large hydroturbine shafts for the Kuibyshev and Novosibirsk Electricity Stations. The shafts are in low-alloy steel, made up of cast flanges (weight 14 tonnes each) and forged shafts (from an 80-tonne solid ingot). Satisfactory welds were obtained, and it was found that the low C content of the steel allows electric slag welding to be carried out without preliminary or post-weld heat treatment, without danger of the formation of cracks.—M. T.

Submerged arc welding L. Knez (*Varilna Tekhn.*, 1958, **7,** (1–2), 4–10) [In Serbocroat] A survey is made of methods and equipment, mainly as used in Central and Eastern Europe, the USA and USSR.—P. F.

Automatic submerged arc welding M. Záruba (*Zeáranie*, 1958, **7,** (9–10), 278–282) [In Czech] Automatic machines, stud welding guns and ceramic fluxes developed in Czechoslovakia are discussed.—P. F.

Automatic arc-welding of heavy boiler plate under molten slag A. Kováf (*Zeáranie*, 1958, **7,** (9–10), 261–270) [In Czech] The technology, machines and electrodes used for the vertical welding of boiler steel plate up to 5 in. thick are described, and details of heat treatments and microstructures obtained in the weld zones are given.—P. F.

Some examples of the economic utilization of electro-slag welding J. Zeke (*Zeáranie*, 1958, **7,** (9–10), 274–278) [In Slovak].—P. F.

Welding of Alloy steels at the Lenin works in Pilsen V. Pilous (*Zeáranie*, 1958, **7,** (9–10), 291–297) [In Czech] The technology developed for the welding of steels used in the construction of power stations is discussed.—P. F.

External characteristics of the current source in welding under a carbon dioxide shield A. G. Mazel' and K. K. Khrenov (**Svarochnoe Proizvodstvo*, 1957, (8), 31–34) Conditions in the welding circuit and their effect on the kind of weld produced are given.

Welding cast components for nuclear-power applications W. H. Rice (*Welding J.*, 1958, **37,** Oct., 971–978) An outline is given of the steel compositions used for nuclear plant pumping systems, the production of cast weldments, and the control and inspection system operated at each stage of production.

Automatic electro-slag welding machines M. Mosný (*Zeáranie*, 1958, **7,** (9–10), 270–274) [In Slovak] Several machines, operating with vertical traverse, developed by the Welding Research Institute in Bratislava are described.

Steel shapes and sections used in river ships, and the welding of steel reinforcements to the bottom cover sheet O. Iždinský (*Zeáranie*, 1958, **8,** (12), 263–368) [In Slovak] Results of experiments carried out by the author on the fatigue behaviour of welded sections used in river boat construction are given. Appropriate welding technology and design modifications are discussed in the light of the data obtained.

Properties and the welding of Czechoslovak Ferritic-pearlitic turbine steels for use at the highest steam temperatures F. Sicha, K. Pawera, and V. Foldyna (*Zvár. Sbornik*, 1958, **7,** (1), 61–85) [In Czech] The metallographic, ageing, creep, tensile and impact properties of steels developed, mainly in post-war years, are described. The method of welding the steels, the properties of the welds, and details of the composition of appropriate welding electrodes are given.—P. F.

Welding alloy steels under bonded fluxes H. C. Campbell and W. C. Johnson (*Weld. J.*, 1958, **37,** Nov., 1081–1085) The use of bonded submerged arc fluxes in pipe welding, in the preparation of overlays or clad surfaces and in welding high-strength low-alloy steels is described.—A. G.

Pure austenitic welding joints resistant to hot cracks (crystallization) B. I. Medovar and Yu. B. Latash (*Avtom. Svarka*, 1957, (2), 32–45) Si, Nb, Zr, C and P may cause hot cracks in these steels. The optimum concentration of Si and C which imparts the utmost resistance was determined. Mn whilst increasing resistance to cracks, reduces the solubility of Cu in austenite. H_2 stimulates crack formation, and O_2, by oxidizing H_2, Si and S increases appreciably the resistance of these steels to cracking.

Special features of welding the first layer of butt welds on gas turbine rotors V. A. Toropov (*Svarochnoe Proizvodstvo*, 1958, (10), 24–26) On the basis of the experiments, a design was developed for a backing ring for welding butt joints on rotors. The experiments showed that one of the methods of avoiding fractures in welded joints at points where the clearances are very restricted between the parts to be welded is to increase the clearances. The design of backing ring may be used for other similar work to be welded from one side only.

On the possibility of using technically pure argon for welding stainless steels with consumable electrodes A. I. Akulov and N. Yu. Pal'chuk (*Avtom. Svarka*, 1957, (2), 50–56) Tests carried out confirm the possibility of using technically pure argon for arc-welding 18–8 type stainless steels. Mechanical and anti-corrosion properties are satisfactory. Chemically pure argon can therefore be replaced by the technically pure gas which means an appreciable saving.

A new method of 'rivet welding' using coated electrodes A. Ya. Brodski (*Eng. Digest*, 1958, **19,** Nov., 482–483; from *Svarochnoe Proizvodstvo*, 1958, (10), 18–21) The disadvantage of the original 'rivet welding' process for the mechanized welding of steel lattice structures, namely that top plates more than 3 mm in thickness must first be provided with countersunk holes, is overcome by a new method developed in Russia, using a coated electrode. When the arc is struck it begins to fuse a hole in the workpiece, thus eliminating drilling completely. Operating details are given.

Welding low-alloy steel castings for high-pressure and high-temperature service N. A. Chapin, C. H. Soldan, and L. W. Songer (*Welding J.*, 1958, **37,** Oct., 979–987) Working details, fully illustrated by photographs and diagrams, are given of the fabrication and welding of large alloy steel castings for use in steam turbines operating at high temperatures and pressures.

The welding of some nonferrous and ferrous tubes to tube sheets R. W. Bennett (*Weld. J.*, 1958, **37,** Nov., 1071–1080) Metallurgical and welding considerations are discussed in relation to the fabrication of heat exchangers for power plants and the chemical and atomic energy industries. The joining of monel, copper, cupro-nickel, copper-zinc alloys and stainless steel tubes to tube sheets of the same metals or of carbon steel is considered.—A. G.

Magnetic flux gas-shielded welding speeds production 400% C. Elliott and M. Misko (*Weld. J.*, 1958, **37,** Nov., 1103–1104) The application of this technique in the production of large electric furnace components has cut welding time by 25%. Other benefits claimed include less spattering and warping.—A. G.

LC welding – its really cool Bernard Welding Equipment Co. (*Can. Metalw.*, 1958, **21,** Aug., 24–26) A system of manual arc welding using flux-coated electrodes and cooling the holder to drain off heat is described.

Developments in the inert-gas tungsten-arc fusion spotwelding process F. W. Copleston and L. M. Gourd (*Brit. Weld. J.*, 1958, **5,** Sept., 394–399) The authors report on tests made on spot welds by the tungsten-arc process. Joints of adequate strength and quality can be produced in mild and stainless steels. It does not, however, seem possible to produce crack-free welds in materials that are naturally subject to hot cracking, e.g. heat-resistant and certain medium-C steels.—T. G.

Welding of galvanized steels I. L. Stern and H. Nagler (*Weld. J.*, 1958, **37,** Nov., 507s–519s) In the fillet welding of galvanized steels intercrystalline cracks tend to form. Causes are discussed and to minimize this cracking, twin arc techniques and the removal of zinc from the web edge by oxygen cutting are recommended.—A. G.

Local heat treatment of joints welded by the electric slag process V. H. Novikov, I. E. Tutov, and A. I. Kondrashev (*Metallov. Obra. Met.*, 1958, (8), 38–43) Joints in 100 t plates and similar parts made of boiler steel (0·22%C) can best be heat-treated after welding by the induction process so as to relieve residual stresses. The optimum conditions are listed.

New power source broadens use for CO_2 welding H. J. Bichsel, E. J. Steinert, and E. R. Gamberg (*Iron Age*, 1958, **182,** Oct. 23, 61–63) A dynamic reactor developed by Westinghouse is stated to permit the use of lower weld currents and the transfer of weld metal in the form of droplets. Larger and cheaper wire sizes may be employed and CO_2 welding in the vertical and overhead position is possible.

The welded steel tube H. de Corta (*Rev. Gén. Méc.*, 1959, **43,** Jan., 13–19) A brief outline is given of various techniques for the manufacture of welded steel tube, with a more detailed description of electrical resistance welding.

Local heat treatment of butt welds to release residual stresses V. I. Novikov (*Avtom. Svarka*, 1958, **11,** (7), 29–35) An experimental investigation was made of the change in the value of the transverse and longitudinal residual

stresses in butt welded joints in low-carbon steel up to 20 mm thick as a result of local heat treatment in relation to the extent of the heat-treated zone, the heating temperature and the dimensions of the butt joint. The effect of unevenness of the heating during heat treatment was also studied. In all cases it was found that while local heat treatment of the joints reduced the longitudinal stresses, it promoted an increase in the transverse stresses. This phenomenon may be explained by the fact that the transverse stresses arise as a result of irreversible plastic deformations of the weld metal and of the heat-affected zone. The zone of plastic deformation during welding is relatively restricted. During local heat treatment not only does this zone fail to disappear, but it even increases, and consequently the causes which set up the stresses are not removed. Thus in the given circumstance local heat treatment, which aimed at strain release, had little influence, and in certain instances had a detrimental effect.—M. T.

The weldability of converter steel melted with the use of oxygen A. S. Astaf'ev (*Svarochnoe Proizvodstvo*, 1958, (10), 12–14) Experiments were first carried out to compare the mechanical properties, cold shortness and tendency to ageing of various converter rimming steels melted with the use of oxygen, with OH killed steel, which showed them to be about equal, but the impact strength was higher and the cold shortness temperature (−30°C) lower for the Bessemer steel. Welded joints in the latter, made by automatic submerged arc welding, were inclined to high-temperature cracking if the S content of the base metal is greater than 0·05%; in general the mechanical properties were as good as those similarly made in OH rimming steel. Top blowing with oxygen of the converter steel produced the best results for impact strength after ageing.—M. T.

The mechanical properties and weldability of vacuum treated Bessemer steel A. I. Krasovsky and V. D. Kodolov (*Svarochnoe Proizvodstvo*, 1958, (10), 8–11) Vacuum treatment of Bessemer steel in the ladle and experimental rolling have shown the possibility of producing high-grade structural steel with high mechanical properties and good weldability. The content of gases (N_2, O_2 and H_2) has a detrimental effect on the mechanical properties of Bessemer steel of the base metal and heat-affected zones, but this content was reduced by vacuum treatment, with a consequent improvement in resistance to ageing and plastic deformation, and a reduction in the critical brittle temperature by 20–50°C. The experiments showed that this improvement was reflected by similar improvements on welding the steel, particularly in the properties of the heat-affected zone. It is considered that vacuum treatment of Bessemer steel is a more economic method of producing high-quality steel than the use of oxygen.—M. T.

Iron-nickel electrodes for cold welding of high-strength and grey iron G. N. Larin, V. V. Bazhenov, and L. M. Yarovinskii (*Svarochnoe Proizvodstvo*, 1958, (10), 5–8) Experiments were carried out on the weldability of high-strength iron of the following composition: 2·92%C; 2·23%Si; 0·56%Mn; 0·08%Cr; 0·003%S; 0·098%P; 0·039%Mg. It was established that: (a) Monophase austenic weld metal (45–55%Ni, balance Fe and impurities) has a strong tendency to the formation of high temperature weld cracking, but these cracks may be avoided by the creation of low melting-point eutectics in the weld metal. (b) These eutectics are necessary to prevent such cracking, but the dominant factor in their prevention is the quantity of eutectics able to fill the intercrystalline vacancies during the crystallization of the weld pool, for such eutectics may also cause a drop in strength and plastic properties and the formation of low-temperature cracking. (c) The most suitable of the eutectics investigated was a complex Si-C structure which both prevented high temperature cracking and preserved mechanical properties and plasticity of the weld metal. Nickel promotes the reduction of cementite in the fusion zone, preserves the plastic properties of the welded joint, and improves its mechanical working properties.—M. T.

Electrodes for welding heat-resisting chromium steel V. V. Bazhenov and T. R. Fedyaeva (*Svarochnoe Proizvodstvo*, 1958, (3), 26–29) Experiments were carried out on the development of electrodes for welding cast austenitic steel (0·12%C, 0·14%Si, 0·51%Mn, 11·80%Cr, 0·89%Mo, 1·9%W, 0·38%V, 0·021%S and 0·027%P) for turbines and boiler equipment operating at up to 610°C. The influences of additions of W, Mo, V, Nb and Ni on impact strength of the deposited metal were individually studied. W, Mo, V and Nb lead to a sharp drop in impact strength, since they increase the quantity of free ferrite, while Ni and very small additions of V increase this strength. By experiment the correct level of the additions was discovered, and C was also increased to 0·15% to eliminate the free ferrite and stabilize the carbide phases at 610°C. The electrode metal evolved had a high impact strength and a long-term strength of 610°C 100 000 h ≈ 10 kg/mm². Welds were operationally reliable in air and in steam at temperatures up to 610°C.—M. T.

Electrodes for welding austenitic heat-resisting tube steel 1Kh18N12T B. I. Lazarev (*Svarochnoe Proizvodstvo*, 1958, (5), 8–11) The article describes experimental work in the development of TsT-15 electrodes which are serviceable for welding in all welding positions, and may be recommended for welding heat-resisting austenitic steels, intended for prolonged operation at temperatures up to 650°C. The mechanical properties of the deposited metal at room temperature after tempering at a temperature of 750°C for a period of 10 h should be as follows: yield point ⩾ 32 kg/mm², ultimate tensile strength ⩾ 60 kg/mm², relative elongation (L = 5 d), ⩾ 24%, impact strength ⩾ 4 kg m/cm².—M. T.

A brief survey of investigations carried out by the French Welding Institute on welding with deep penetration electrodes A. Gaubert (*Varilna Tehn.*, 1958, **7**, (1–2), 1–4) [In Serbocroat.].—P. F.

Baking of coated arc welding electrodes in gas fired oven (*Ind. Heat.*, 1958, **25**, Sept., 1805–1808, 1816) In the plant described the manufacture of coated arc welding rods is fully automatic. A three pass gas oven is used having 5 heating zones and fitted with automatic temperature control.—A. G.

The beading layer of high-chromium iron with powder electrode wire V. V. Podgaetskii and V. I. Kolisnyk (*Avtom. Svarka*, 1957, (2), 103–106) The composition of a powder wire, producing, when fused under flux, an alloy containing 3–4%C and 14–15%Cr is given. A layer is obtained of 68–70 R_c hardness to a thickness of a few mm. The wire is suitable for automatic welding.

Iron powder in welding electrodes T. Lundberg and D. L. Mathias (*Pamphlet by Höganäs-Billesholms AB, Sweden*, 1958, pp. 142) [In English and German] The development of iron powder welding rod, the use and economies and the properties of the weld produced are reviewed. The use of these electrodes in the US is then discussed with considerable detail on the methods employed and the practical applications.

New fluxes for arc welding K. V. Lyubavsky and E. P. L'vova (*Svarochnoe Proizvodstvo*, 1958, (10), 1–5) Experiments were carried out on the submerged arc welding of high-alloy austenitic steels using austenitic electrodes and new types of ceramic fluxes. These afford appreciable advantages over ordinary ceramic fluxes, since gases are not liberated during welding, and the layer of scale is easily and completely removed from the surface of the weld. These fluxes based on fluorides and containing a small content of ferrite or austenite formers, dependent on the electrode composition, for the purpose of producing a certain quantity of ferrite in the initial structure of the weld metal, are easy to prepare, and afford a further means of alloying the weld metal.

Knowledge of metal structure vital in welding W. C. Winegard (*Canad. Metalw.*, 1958, **21**, July, 34–39) Welding procedures must be based on an adequate knowledge of the crystallography of the metal involved, the microstructure of the original material, and the chemical composition of both the parts to be welded and the filler metal.—T. G.

Fundamental steel metallurgy applied to welding G. B. Craig (*Canad. Metalw.*, 1958, **21**, June, 52–62) Because of the complexity of the welding process – metallurgically speaking – the specific problems in the welding of steel are discussed under the headings: Fusion, structure, allotropy, Fe-C phase diagram, *TTT* curves, tempering, phase diagrams, residual stresses, graphitization, and the properties of various types of steel.—T. G.

Metallurgical features of welds on austenitic acid resisting steels with 23% chromium and 23–28% nickel Yu. I. Kazennov and L. P. Kolosova (*Avtom. Svarka*, 1957, (2), 22–31) The features considered accompanying the crystallization of pure austenitic steel welding joints are the chemical changes in the composition of the welds and their resistance to the formation of hot cracks. Various types of steel are considered in turn and the influence of additions of alloy elements Mn, Cu, Mo, Ti and W are investigated.

Weldability and notch toughness-I K. Winterton (*Canad. Metalw.*, 1958, **21**, June, 40–50) Many welding processes, in particular arc welding, have a close relationship with casting. Major segregation is responsible in both for the collection of impurities in the central zone and this is related in both cases to columnar growth. The effects of sulphur in the welding of steel are also discussed. Weld stresses are set up leading to hot-cracking and fissuring, the latter is attributed to the effect of H_2 test procedures using notched samples are described and their value is discussed.—T. G.

A comparative study of the weldability of steels used in power plant A. Zapletálek (*Zeár. Sbornik*, 1958, **7**, (2), 146–188) [In Slovak] The causes of failure of a 0·45%Mo steel tube which had been working for some time at 450–500°C were determined. Incorrect bending, welding and flanging of the tube were found to be the main causes. It is shown that a substitute steel for high steam temperatures, which does not contain Mo, is entirely adequate, having properties in all respect similar to those specified for the Mo steel. Correct welding technology and the choice of welding electrodes are considered.—F. F.

The influence of nitrogen on the liberation of hydrogen during crystallization of the weld pool L. S. Sapiro (*Avtom. Svarka*, 1958, **11**, (9), 56–60) The results are given of research into the combined influence of N_2 and H_2 on the porosity of welds. The processes of the origin and growth of a gaseous nucleus in a liquid are extremely complex, but in a simplified form it can be considered that such a nucleus tends to have its origin on such separation planes where minimal intermolecular forces of attraction operate in the boundary layer, i.e. where the adhesion is minimal. At low contact angles adhesion is great, but at high contact angles adhesion approaches zero, the gaseous nucleus is formed and the gas is liberated on the separation planes. Where such conditions exist (at high contact angles between the nitrides and the molten metal) and there is a high content of H_2 in the weld pool, it will be liberated in the gaseous phase. N_2 acts as a catalyst for this liberation of H_2, which causes weld porosity.—M. T.

Special features of intergranular segregation of sulphur and phosphorus in welded joints L. A. Poznyak (*Avtom. Svarka*, 1958, **11**, (7), 65–71) As distinct from low-carbon steel welds, in which all the S is to be found in supersaturated solid solution, in medium-carbon steel welds diffusion of sulphides from the solid solution occurs; readily fusible sulphide eutectics in the form of intergranular laminates are formed only at high S contents (>10%). Intergranular segregation of P is observed only in welds with high contents of C and P (>0·1%). Metallographic and electron microscope analyses were carried out on submerged arc welds, and radioactive S and P were used to trace distribution. Increased C contents (>0·25%) promote P segregation, which more frequently occurs in the upper part of the weld where the crystallization rate is lower.—M. T.

The fusion and transfer of the (electrode) metal during CO_2 arc welding with a thin electrode wire A. G. Potap'evsky (*Avtom Svarka*, 1958, **11**, (7), 52–59) A study was made of this subject using a 0·5–1·2 mm diameter

electrode wire, the distribution of energy in the arc gap, and the influence of the individual welding parameters on the fusion and transfer of the electrode metal. It was established that 90·1–98·7% of the energy is expended in igniting the arc. Transfer of the metal causes short-circuiting of the arc gap and is substantially dependent on the dynamic characteristics of the source of current. Spattering is substantially dependent on the welding parameters and the dynamic characteristics of the source of current.—M. T.

Photo-electric control of the level of heating of the metal during seam welding A. A. Trushchenko and O. V. Sukhov (*Avtom. Svarka*, 1958, (7), 44–47) The results are given of successful experiments in the use of a photoelectric pyrometer for continuous determination of the temperature of the metal close to the point of contact between the electrodes and the components to be welded. A relationship was established between the surface temperature of the welded joint and the dimensions o the centre of the individual spot. While satisfactory welds were obtained with water cooling of the wheels when the surface of the joint was heated to 840–940°C, the strength of joints made without cooling of the wheels was about 50% greater than those made with water cooling. A photoelectric pyrometer may be used as the measuring element for continuous automatic control of the welding conditions.

Mechanical properties of joints in acid resisting Kh 17 (17% Cr) steel, obtained by CO_2 arc welding with an austenitic steel electrode N. I. Kakhovsky (*Avtom. Svarka*, 1958, **11**, (9), 37–39) The article gives a series of data on the results of tests of the mechanical properties of this steel at temperatures up to 800°C and of the welded joints obtained, which had the necessary chemical composition and mechanical properties to meet the demands of the normal applications of this steel.—M. T.

The primary crystallization of the weld metal after fusion in welding M. I. Razikov (*Atom. Svarka*, 1958, (9), 60–62) In the welding of steels the fused austenite grains of the base metal are lined by growing columnar dendrites from the weld metal, and therefore the grain size of the weld metal seams depends to a large extent on the size of grains in the base metal along the line of fusion at the moment of the growth of the dendrites. The most effective methods of reducing the dimensions of the dendrites in the weld metal are those ensuring minimum growth of grains in the base metal.

The impact strength of the metal of the heat-affected zone of welded joints in high-chrome steel B. A. Rabotnov (*Avtom. Svarka*, 1958, **11**, (9), 20–23) Results are given of tests of the impact strength of various portions of the heat-affected zones in welded joints in 13% Cr steels. It is shown that the most brittle portions of the heat-affected zone lie at a distance of 1–3 mm from the boundary of the fusion zone.—M. T.

The influence of some technological and structural factors on the strength of welded joints of high-strength structural steels O. L. Bendryshev (*Metallov. Obra. Met.*, 1958, (11), 51–56) The joints were tested for comparative resistance to bending and fatigue both for smooth and for corrugated surfaces; for the influence of normal pressures on contact surfaces, their strength, the influence of different types of corrugation, grooving, etc. and of cyclical loads.

On the properties of welded joints in Kh18-N12M3T austenitic steel on its resistance to acids G. A. Ukolov (*Avtom. Svarka*, 1957, (2), 46–49) 0·5–0·65% Niobium is added to increase resistance to intercrystalline corrosion. Special electrodes of type NZh-13 have been evolved for these welds which ensure the alloying of the weld metal with Nb thus imparting good mechanical and anticorrosion properties.

Metallurgy of electric resistance welded steel pipe J. G. Parr (*Can. Min. Met. Bull.*, 1958, **51**, Oct., 624–629) Effects of mill variables on weld structure are investigated and the metallographic structures as affected by heat input, mill speed, pipe contour, edge condition and steel defects are illustrated and discussed.

Anticorrosion properties in oxidizing solutions of stainless steel welds B. I. Medovar, N. A. Langer, and M. N. Kurtenov (*Avtom. Svarka*, 1957, (2), 57–60) The chemical compositions of suitable wire electrodes for each type of steel are listed as well as the specific loss in weight in g/m²/h in various concentrations of HNO_3 and $HNO_3 + K_2Cr_2O_7$.

Welded ship construction – records of common fractures and their causes H. R. Gibbs and G. M. Boyd (*Trans. Inst. Eng. Ship. Scotland*, 1957–1958, **101**, 282–316) Lloyds' register classification system for fracture is described and various cases of failure are given as examples of the use of such records.

The formation of inhomogeneities in the weld fusion zone on heating to 500–700°C L. S. Livshits and S. I. Panich (*Svarochnoe Proizvodstvo*, 1958, (4), 22–25). 1. The heating of welded joints under working conditions to temperatures within the range of 500–700°C may lead to the migration of carbon from one part of a welded joint to another and the formation of marked chemical and structural inhomogeneity in respect of carbon in the fusion zone. 2. The migration of carbon during heating within the temperature range indicated is governed by the presence in one part of the welded joint of excess atoms (not combined into carbides) of an element capable of forming more stable carbides than those elements which are contained in another part of the welded joint. Migration of carbon may even occur where both parts of the welded joint contain identical alloying elements, but where in one part there is an excess of free atoms of a carbide-forming element, and in the other an excess of free carbon atoms. 3. A method of calculation is propounded for determining the possible formation of inhomogeneity in respect of carbon in the weld fusion zone in relationship to the content (atomic%) of the alloying elements in the weld metal and the parent metal. 4. When the formation of carbon inhomogeneity occurs in the fusion zone of welded joints after prolonged heating at 500–700°C, it is recommended that such joints should be subjected to post-weld heat treatment up to 950°C, which will lead to the equalization of the concentration of carbon and the elimination of the existing inhomogeneities. The above conclusions are drawn from a study of carbon migration during experiments for up to 100 h at 700°C on low-alloy steels.—M. T.

On brazing with Cu-P brazing alloy P. Slyško (*Zváranie*, 1958, **7**, (8), 245–248) [In Slovak] A metallographic study of phases present in brazed joints in non-ferrous metals and low-carbon steels, when Cu-P brazing spelter was used, shows this spelter to be suitable for non-ferrous brazing. Owing to the formation of brittle phases the spelter is not recommended for steels; it cannot therefore be used to replace silver solders.—P. F.

Metallurgy of bonding in brazed joints. Part I. Base metal – filler metal interaction excluding compound formation N. Bredzs and H. Schwartzbart (*Weld. J.*, 1958, **37**, Nov., 493s–498s) The effects of brazing temperature, filler metal composition and carbon content of the base metal on the solution of the steel base metal have been investigated together with the solidification characteristics of the filler metal layer.—A. G.

Crack formation in brazing 1Kh18N9T steel with L62 brass A. I. Gubin (*Vestnik Mashin.*, 1958, (12), 58–61) An analysis of experimental results has shown that the strength of the steel was reduced equally by the different fluxes used, and that the reduction varied between 11 and 14%. The fracture of specimens occurred without formations of waists. The use of an underlayer of copper and nickel 3–5μ thick does not influence the effect of molton brass on the strength of steel. Under compression only, no appreciable penetration of brass into steel is observed. Under tensile stress, however, the diffusion process along the grain boundaries of the steel is accelerated all along the contact surface. This may explain the formation of surface microcracks.

Bonding steel with plastic adhesives K. Möhler (*VDIZ*, 1959, **101**, Jan., 1–8) An account is given of the construction and behaviour in service of an experimental bridge, supporting pipes and carrying foot passengers, which was fabricated by bonding the structural members with plastic adhesives. The results of tests show that much higher bonding strengths are obtainable with cold-curing plastic cements.

Oxy-gasoline cutting torch works fast, lowers cost W. Czygan (*Iron Age*, 1958, **182**, Oct. 23, 66–67) A safe and reliable torch for oxygen-petrol cutting is said to have been developed. The advantages of this method of cutting are listed.—A. G.

Automatic line tracing in oxygen shape-cutting machines A. F. Chounard and E. L. McDonald (*Welding J.*, 1958, **37**, Oct., 988–990) The economies, design and operation of an electronic system which has been developed for the automatic scanning of ordinary pattern drawings in an oxygen profile-cutting machine.

Flame cutting and jigging for a nuclear power station J. W. Gethin (*Brit. Weld. J.*, 1958, **5**, Sept., 400–407) The author discusses the many problems – particularly accuracy of fit and the preparation of the surface for subsequent welding – involved in the demand for gas cutting plant and jigging equipment required in the manufacture of nuclear power plant.—T. G.

MACHINING AND MACHINABILITY

Metal cutting: A research problem W. B. Rice (*Trans. Eng. Inst. Canada*, 1958, **2**, Dec., 149–152) Previously published formulations of the cutting process are reviewed and compared with actual measurements. The approach to a new model is suggested. The minute scale of the process is stressed.

Stability of the process of metal cutting M. E. El'yasberg (*Izvest. Akad. Nauk. Otdel. Tekn.*, 1958, (9), 37–52) The stability of the process of metal cutting is one of the fundamental conditions which should be satisfied by the system consisting of the machine tool, cutting tool and the object to be machined. Nevertheless, no satisfactory theory exists at present which explains vibration phenomena during the machining process. The speed of the plastic deformation of metal when chips are removed is about one-sixth of the speed of sound, but it is many times greater than the normal cutting speed. The author assumes that the process of metal deformation is of a discontinuous character. On the basis of his hypothesis he considers various cases of metal cutting, discussing systems with one, two or many degrees of freedom. Differential equations and methods of their solution are derived. In order to verify theoretical considerations, tests were carried out by using a lathe with a specially designed tool holder of variable rigidity. Holder vibrations were recorded by the appropriate electronic equipment and an oscillograph. Cutting speeds (steel 45) varied approximately from 30 to 56 m/min. The author comes to the conclusion that the theory proposed by him satisfactorily explains the main experimental vibration phenomena observed during the machining of metals.—S. S.

Relation between the cutting force and the strength of grey cast iron S. S. Nekrasov (*Vestnik Mashin.*, 1956, (4) 59–62) No plastic deformation can be observed under the microscope in sections of grey cast iron. This agrees entirely with the hypothesis that for brittle materials the main component of the cutting force is in direct ratio to the ultimate compression strength. Experiments carried out to elucidate this proposition are described and the tabulated results, used for a comparison of the actual and calculated values, confirm the hypothesis.—L. H.

The study of chip formation: The problem of plastic deformation as deduced from the theory of discontinuous chip removal G. Carro-Cao (*Microtechnic*, 1958, **12**, Dec., 331–337) Work at Pisa is described. The three-zone theory of Lee is experimentally confirmed and the adequacy of present methods for force determination for practical use is shown. The effects of tool changing time are noted.

More knowledge of cutting-tool geometry needed S. W. Lovejoy (*Canad. Metalw.*, 1958, **21**, July, 8–11) The author explains the fundamentals of cutting and cutting-tool design, as

the methods of using cutting tools are constantly changing. With the introduction of new materials this factor has become very important.—T. G.

New form of lathe cutting tools G. M. Ryvkin (*Stanki Instr.*, 1959, (2), 29–30) Special shapes of cutting tools have been tested. These were evolved in order to increase stability in operation. Some new shapes are recommended for universal lathes, subject to tests on an industrial scale.

Tool-up for high-speed cutting – II W. G. McIntosh (*Canad. Metalw.*, 1958, **21,** June, 22–23) Recommendations are made for the useful fields of application of ceramic tools, at the same time pointing out applications where these very brittle materials must lead to failure and disappointment. However, ceramic tools give – correctly used – the highest cutting speeds, approximately twice those obtainable with cemented carbides.—T. G.

Efficiency of cutters with hard alloy blades working with steel 65G V. A. Parizhskii (*Vestnik Mashin.*, 1958, (9), 47–48) This steel contains an increased percentage of manganese and is much used in agricultural machinery. The cutting blades were made of eight different types of hard alloys and the results show that this steel has a very low machinability, approximately half that of steel type 45.—L. H.

Selecting a criterion for the wear of cutting tools in precision turning A. P. Dobrorez (*Vestnik Mashin.*, 1958, (12), 52) The radial wear only is considered in fine precision turning, i.e. in the direction normal to the surface of the work-piece. From tests with tool steels it has been established that curves for radial wear plotted against the lengths of metal cut are almost linear, whilst curves for the wear of the rear surface plotted against the same lengths are irregular.

Cutting manganese steel G12 in the heated state V. G. Lynbimov (*Stanki Inst.*, 1958, **29,** (7), 27–29) The effect of heating the austenitic Mn steel G12 to temperatures up to 600°C on cutting rates is examined.

Remarks regarding the causes of fissures during grinding and methods to detect them: II H. Schwartz (*Met. Constr. Masini*, 1958, (8), 669–674) [In Rumanian] The following factors are considered the main causes of fissure formation, although completely unrelated except by the great amount of heat generated between stone and metal during grinding, causing modification of macro- and microstructures. (a) deterioration of the grinding stone, (b) the contact surface between stone and part, (c) the time of operation, (d) the ratio between the speed of the stone and the abrasive disc, (e) the profile of the abrasive disc, (f) the pressure between the part and the stone. A proper selection of tools and machines must be made. These fissures can be detected by magnetic methods, by etching, with oil and chalk, sand blasting and by immersion in paraffin, with penetrating fluorescent liquids, and so on.

The effect of oil emulsions on the cutting properties of tools A. Bulat and R. Sniechowski (*Prace Inst. Mechaniki*, 1955, **5,** (15), 56–66) Effects of some oil emulsions on the cutting properties of tools in turning, boring, milling and grinding operations are described. The effect of the concentration of the oil (2·5%–25%) and the underlying economy is examined

Are you getting the most from your form milling cutters C. Sharp (*Iron Age*, 1958, **182,** (15), Oct. 9, 88–89) In milling, a heavier feed may both shorten machining time and increase cutter life. Advantages may also accrue from the use of fewer teeth or by adopting a climb milling technique.—A. G.

Cutting-fluid action and the wear of cutting tools M. E. Merchant (*Institution of Mechanical Engineers, Conference on Lubrication and Wear, London*, 1957, 566–573) Heat control by the cooling effect of the fluid and by the reduction of friction is shown to be the main factor in the reduction of tool wear. The friction is reduced by chemical action on the newly formed, highly strained chip surface. Besides the agreement with calculation, direct detection of the reaction products and catalytic effects on chemical reactions by the cutting process are evidence of this. The radioactive tool test method is evaluated and its accuracy and rapidity confirmed.

About wear on cutting tools H. Opitz (664–669) Modes of wear of carbide tools and the heat and thermoelectric effects involved were examined. Feeding oxygen to the interface area reduced tool life but this was partly rectified by adjustment of the thermoelectric circuit.

Applications of ceramic cutting materials and causes of wear of hard metal tools H. Opitz (*Microtecnic*, 1958, **12,** Oct., 267–288) A review of the development, properties and uses of ceramic cutting materials.

Machinability of hardened cast iron cutters with blades of VK2 and TsM332 V. A. Kacher (*Stanki Inst.*, 1958, (7), 26–27) Data are given for cutting speeds of blades made from the alloys VK2 and TsM332, and the results are discussed.

The use of carbon dioxide for increasing the life of cutting tools A. I. Isaev and N. I. Tashlitskii (*Vestnik Mashin.*, 1955, (11), 42–48) Experimental data have shown that CO_2 fed to the cutting zone allows an increase in the cutting speed of 15–20% in high-speed cutting of difficultly machinable ferrite-pearlite alloy steels with a breaking strength above 70 kg/mm². With an increase in the depth of the cut, the efficiency of CO_2 increases slightly. An increase in the width of the cut does not affect the use of the gas, but in view of the greater surface the supply of gas has to be increased.

Machinability of stainless steel Ya. Kh. Kostyukov, A. K. Baev, and V. N. Verezub (*Vestnik Mashin.*, 1956, (1), 38–42) On the strength of appropriate experiments, the article suggests the most suitable materials for tools, and their geometry. The experiments served to study the wear and blunting of tools, the deformation of the worked layer and the condition of the worked surface, and from the results obtained the author constructs a table from which the conditions of the operation can be selected for any given requirements.—L. H.

The reaming of precision perforations G. S. Andreev (*Vestnik Mashin.*, 1956, (3), 36–41) The experimental material was Kh14N14V2M steel, a medium machinable steel in the austenitic heat-resistant range. The reaming was carried out on a vertical drill driven by a 7·5 kW motor. The reamers were made of steel R18, R9 and U12A. Under conditions described special recommendations are made regarding the type of reamers and the conditions of the operation.—L. H.

Tool steel failures: Cause and remedy – I B. M. Hamilton (*Canad. Metalw.*, 1958, **21,** June, 8–14) The author discusses the factors involved in the selection of the most suitable grade of steel, its heat-treatment, the proper grinding of the hardened tools, design and operation. **II** (July, 14, 50) The reasons for failure of tool steels are very briefly discussed. Simply changing to another source or grade of steel is no remedy for bad design of the tools.—T. G.

The synthetic grinding materials silicon carbide and electrocorundum A. Schneider (*Radex Rund.*, 1959, (1), 421–433) The advantages of synthetic compared with natural abrasives are pointed out, and the manufacture and properties of silicon carbide and electrocorundum are described.

Calculation of the temperature of the surface during grinding S. G. Red'ko (*Stanki Inst.*, 1959, (2), 26–29) The temperature and dimensions of the filings removed by the abrasive grains do not influence the surface temperature of the piece in work. A change in the rate of feeding and depth of grinding shows only a change in the number of heat pulses, and with the removal of the abraded grains from the metal the temperature remains constant, bearing no relation to the temperature of the filings or to their dimensions. The condition of the abraded grains depending on the setting and on the degree of bluntness of the grinding disc do influence the temperature of the surface in work. The heat accumulating from all influences, decreases with an increase in the peripheral speed of the disc, in the arc of contact, in the number of grains per mm², and with many other factors. The temperature is higher, the higher the number of abrasive grains working simultaneously and the smaller the distance between them.

CLEANING AND PICKLING

Cleaning and preparation of metals prior to electroplating. Effect of oxide films. XI. Effect of oxides on the adhesion of electroplates H. B. Linford and A. Venkateswarlu (*Plating*, 1958, **45,** July, 728–733) Ni on Cu was studied. Above a critical oxide thickness the plate peels spontaneously.

Washing-drying machine for tinplate and thin dipped steel sheets A. A. Ovchinnikov (*Vestnik Mashin.*, 1955, (4), 67–68) The sheets are dried by the heat accumulated in them during washing in the bath with hot water. The moisture left on the surface quickly evaporates when the sheets leave the bath. Hot air is pumped in addition so that simultaneously with drying, the washing of the sheets takes place with the elimination from the surface of any sludge left from the acid bath. Drawing and specifications of the apparatus are given.—L. H.

High pressure cleaner (*Ind. Eng. Chem.*, 1958, **50,** Nov., 33A–34A) Burroughs Corp. has developed a method of treatment of small parts by a detergent spray, replacing copper plating or oil coating previously used for their protection during shipping. Metaphosphate-chromate solution is used.

Special purpose shot blasting installations (*Corros. Prev.*, 1958, **5,** Mar., 55–58) Equipment is described for the mechanical cleaning of steel strip, and of large castings, and installations for air-operated shot-blasting of large parts where mechanical cleaning is not required. The use of monorail conveyor plant is described.

Regeneration of the electrolyte for electrolytic polishing of carbon steels. Part II – Removal of iron T. Zak and J. Socha (*Prace Inst. Mechaniki.*, 1955, **5,** (15), 51–55) Methods used to remove iron from baths containing chromic acid are reviewed. The effect of H_2SO_4 concentration on the electro-osmosis of Fe^{+++} was investigated. 5–10% H_2SO_4 concentration was found to be the most suitable. For the electroplating of iron without diaphragm, the best current density is 1·7–1·9 A/cm².

On the mechanism of the alkaline oxidation of steel A. V. Shreider and A. G. Arakelov (*Zhur. Prikl. Khim.*, 1958, **31,** (11), 1673–1678) By means of labelled atoms it was shown that the formation of oxide films during the alkaline nitrite polishing of steel is due chiefly to the direct oxidation of the iron. In the substances forming this oxide film, the most unessential role belongs to the iron oxides which originate during crystallization from the solution. The fall in the oxidation potential of the solution increases the influence of the deposits of the secondary iron corrosion products in the solution by the formation of oxidation products on the metal surface.

Factors affecting the pickling rate of hot rolled steel strip J. LeBas (*BHP Techn. Bull.*, 1958, **2,** Sept., 10–16) The influence of strip contour, coiling temperature, rate of cooling after scaling, scale breaking and acid concentration and temperature on the pickling rate of hot rolled steel strip are investigated.

PROTECTIVE COATINGS

Finishing pointers: Sampling a plating solution J. B. Mohler (*Met. Fin.*, 1958, **56,** Nov., 72, 81) Sampling practices are indicated and the effects of slow solution of components and degree of mixing are considered.

Standard methods of testing galvanic coatings M. Marić (*Zaštita Mat.*, 1958, **6,** (7–8), 300–304) [In Serbochroat] Methods in current use for examining the roughness, corrosion resistance, and other physical and mechanical properties are surveyed, mainly in the light of BS, DIN and ASTM specifications.—P. F.

Tolerance and fit of electroplated parts A. S. Smirnov (*Vestnik Mashin.*, 1956, (2), 14–18) An experimental study concerning the dimensions of parts under electroplated layers so that the finished objects should be interchangeable. It considers oxidized aluminium parts, zinc- nickel- and chromium-plated steel,

copper and copper alloys and cadmium plated and burnished steel objects.—L. H.

On the brightness of electrolytic deposits as related to their internal and external structures K. M. Gorbunova and A. A. Sutyagina (*Zhurn. Fiz. Khim.*, 1958, **32**, (4), 785–789) Experimental data obtained from investigations into the effect of the alternating current on electrocrystallization of Ni, Zn and Cd from sulphuric acid solutions with additions of different surface-active substances show that the structures of the deposits (dimensions, form, shape of crystal boundaries and their reciprocal arrangement, texture) and the coefficient of reflection are not dependent on the dimensions of the crystals nor on the reciprocal arrangement. From X-ray analysis and electron microscopical investigations it is inferred that the greatest influence in the appearance of this polish is played by the contours of the separate crystals as well as by the deposits as a whole.

Trends in waste disposal D. G. Foulke (*Met. Fin.*, 1958, **56**, Nov., 54–57) Plating waste disposal with special reference to water conservation is reviewed.

An electrochemical method of obtaining an index of porosity of metal coatings M. Clarke and S. C. Britton (*Trans. Inst. Met. Fin.*, 1958/59, **36**, Winter, 58–66) A porous metal coating is treated anodically so that current passes via the base metal exposed at the pores. The resistance of the electrolyte in the pore channels is determined from a plot of potential against current and gives a numerical value for porosity in good agreement with other methods.—A. G.

A review of local authority bye-laws on finishing trade effluents Lord Meston (*Prod. Fin.*, 1957, **10**, Feb., 54–62; Mar., 100–103, 130; Apr., 74–83, 126; May, 81–85; June, 104–108; July, 98–102; Aug., 100–106, 126; Sept., 90–93; Nov., 90–97; Dec., 76–80; 1958, **11**, Jan. 80–85; Mar., 102–107; Apr., 74–78; May, 82–88; June, 86–92, 118; July, 66–69, 90; Aug., 68–72; Sept., 66–73; Nov., 74–79; Dec., 78–82. Index by counties, p.82.

Influence of the conditions of electrolysis on the structure and resistance to wear of electrolytic iron coatings Yu. N. Petrov (*Metallov. Obra. Met.*, 1958, (12), 53–56) Experimental results established the optimum conditions of electrolysis ensuring compact fine-grained and wear-resistant coatings required in machine repairs. Two chloride-containing electrolytes are specially recommended.

Protection of springs of steel EI723 from high temperature oxidation T. I. Volkova and Yu. N. Griboedov (*Metallov. Obra. Met.*, 1958, (5), 37–40) The surface of this steel, with 0·2%C, 0·74%Mn, 0·28%Si, 2·3%Cr, 1·0% Mo, 0·45%V and 0·01%P and S, scales above 500° in steam turbine service. It was quenched after 1 h at 1050°C and tempered 6 h at 650° in air with or without surface impregnation with Cr or Al, the processes being described, and tested for corrosion and relaxation after long periods in air at 610°. Relaxation resistance is lowered by all treatments, least by chromizing at 1000°C for 8 h, forming a 7–12 micron layer. Metallographic examination was also employed and hardness measured at various depths below the surface. Carbon depletion did not occur.

Chromium plating baths on a chromium sulphate base C. Firoiu (*Met. Constr. Masini* 1958, (9), 751–758) [In Rumanian] The bath proposed by T. Yoshida (*J. Chem. Soc. Jap.*, 1953, **56**, (3), 140–142; (10), 735–737; (12), 912–914; 915–917, also in **57** and **58**) was used for comparison against a new bath proposed by the author as follows: $Cr_2(SO_4)_3(NH_4)_2SO_4$, $(NH_2)_2CO$, H_3BO_3, CrO_3 in definite proportions giving a pH of 3·5, with 10–25 Amp/dcm² current density and current efficiency between 6·5–11% working at a temperature between 35–45°. Substantial advantages are claimed for this bath in comparison with the Japanese baths, due to the introduction of Co sulphate.

Studies on electrodeposited chromium films. II. On the distribution of hardness N. Awa and O. Fusida (*Nippon Kinzoku*, 1957, **21**, Nov., 625–628) The distribution of plate thickness and hardness over a plated specimen were determined; after 6 h plating a maximum variation of 8·5% in hardness resulted. After grinding and lapping to a uniform accuracy of ± 0·001mm, uniform hardness was obtained.

Investigation of the regeneration of chromium baths K. Szmidt and Z. Kolanko (*Prace Inst. Mechanski*, 1955, **5**, (15), 41–50) The composition and contents of Cr baths are discussed. Methods of regeneration are reviewed. The authors investigated: the use of the ion-exchange materials 'Dovex 50', KP-38, KS-12, Escarbo 1465 and Wofat F; a method based on the precipitation of contaminants with calcium chromate is used.

Developments in decorative plating C. H. Sample (*Plating*, 1958, **45**, July, 721–727) Bright Cr, bright and semi-bright Ni and buffed dull Ni are described and compared, and an account of exposure tests at Kure beach is given.

The chemistry of Watts nickel plating solutions E. B. Saubestre (*Plating*, 1958, **45**, Sept., 927–936) A review of the electrochemistry of each bath constituent is given (30 refs.).

The properties of nickel electro-deposited from a sulphamate bath D. A. Fanner and R. A. F. Hammond (*Trans. Inst. Met. Fin.*, 1958/59, **36**, Winter, 32–42) The effects of some variables on the properties of nickel deposited from a sulphamate bath are described and optimum conditions for minimum internal stress are defined. Such deposits are compared with nickel deposited from a Watts-type solution.—A. G.

Some developments in barrel nickel plating B. E. Bunce (*Electropl. Met. Fin.*, 1958, **11**, Nov., 389–397) The results of a study on the improvement of barrel Ni plating – with respect to speed and quality – are reported and discussed. A review of published information on solutions, equipment and operating data is included.—T. G.

Regeneration of nickel plating baths K. Szmidt, Z. Kolanko, and J. Latoszek (*Prace Inst. Mechaniki*, 1955, **5**, (15), 36–40) Methods of purification of nickel baths are discussed. The method used by the author is based on the formation of precipitates of all impurities by the use of aqueous solutions of ammonia. The concentration of zinc remaining was 0·012% which is quite tolerable.

On the connexions between the texture of the electrolytic nickel deposits and their properties G. S. Vozdvizhenskii and R. S. Saifullin (*Zhurn. Fiz. Khim.*, 1958, **32**, (4), 831–832) The investigations carried out have not shown any direct connexion between the preferential orientation of nickel crystals along the [001] axis and their properties. The reason is obviously the masking effect of the grain size of these deposits. Further investigations must be carried out for this purpose with specimens of identical grain size.

Preparation of iron alloys nickel-plated from chloride electrolytes V. V. Sysoeva (*Zhurn. Prikl. Khim.*, 1959, **32**, (1), 128–132) The following recommendations are made on the basis of the experimental results: Electrolyte $\Sigma[Fe^{++}]$, $[Ni^{++}]$ — 100 g/litre (calculated on the metal weight in the form of chlorides) citric acid — 15 g/litre ph = 3± 0·01; c.d. 40 A/cm², temperature 70°. The anode current density for the iron and nickel anodes is adjusted to the ratio of the metal in the alloy for a given composition of electrolyte from the data supplied.

Continuous galvanizing line for steel strip (*Corros. Prev.*, 1958, **5**, Aug., 43–45) Some details and illustrations of the new continuous galvanizing line at the Ebbw Vale plant of Richard Thomas and Baldwins Ltd are given.

The effect of various factors, particularly plant construction, on the quality of the tin coat J. Teindl (*Sbornik, Ostrava*, 1958, **4**, (3), 233–251) [In Czech] Various factors in the production technology, as well as in the design of the tinning plant, which influence the quality of the coating on tinned sheet are discussed in detail.—F. F.

Automatic bright cadmium plating in a trade finishing shop (*Electropl. Met. Fin.*, 1958, **11**, Nov., 403–405) A fully automatic bright cadmium plating machine with hydraulic operation, the layout of the plant and the operation cycle are described.—T. G.

Study on aluminium coated steel. VIII. Influence of the chemical compositions of steel and the aluminium bath on oxidation at high temperature T. Saga and M. Yasui (*Nippon Kinzoku*, 1957, **21**, Nov., 636–640) Hot-dipped Al coatings on Si- or Cr-steel have better resistance to high-temperature scaling than on plain carbon steel. Coatings alloyed with Si or Be showed lower heat-resistance, the Be-containing layer being slightly superior. In cyclic heating and cooling, the Si-containing layer adhered less to the base than the Be-containing layer. Cracks on the layer became finer with increase in alloy content.—F. E. J.

Metallizing – hot metal spraying S. Lajšić (*Zaštita Mat.*, 1958, **6**, (7–8), 279–283) [In Serbochroat] The technology and applications of hot metal spraying is discussed.—F. F.

Metallization by projection (*Met. Elect.*, 1959, **23**, Feb., 85–90) Techniques of metal spraying and properties of the coatings produced are described.

Carbonate deposits for pipe protection R. F. McCauley and M. O. Abdullah (*J. Amer. Water Works Assoc.*, 1958, **50**, Nov., 1419–1428) A study of protective calcite-limonite–siderite coatings on cast iron in a laboratory recirculating apparatus is reported. High flow rates produced hard, durable coatings, static deposits were easily removed. Presence of colloidal $CaCO_3$ gave better coatings but suspended crystals did not.

Phosphating treatments. A comprehensive patent literature survey E. C. Tinsley (*Met. Fin.*, 1958, **56**, May, 97–100; June, 72–75, 77; July, 66–69, 73; Aug., 70–72; Sept., 71–73; Oct., 72–73, 82).

Protective coatings based on bitumen J. Stanford (*Corros. Prev.*, 1958, **5**, Mar., 62–64) The use of bitumen as a protective coating is outlined, its versatility emphasized and the importance of surface preparation pointed out.

Neoprene as lining material for the protection of chemical plant H. Tixier (*Werks. Korr.*, 1959, **10**, Feb., 70–73) Merits and properties of Neoprene are reviewed and the techniques of lining – including surface preparation, lining with foils and adhesive under application of mechanical pressure and finally the testing by high-frequency discharges – are discussed and described.—T. G.

Protective organic coatings for steel L. J. Nowacki and E. R. Mueller (*Ind. Heat.*, 1958, **25**, Sept., 1810–1816; Nov., 2308–2316) A classification of the types of organic coatings for the protection of steel is presented together with notes on their applications. Finishing systems for the coating of steel are discussed including the stages of surface preparation, application of successive coatings and final curing.—A. G.

Reinforced plastics for corrosion control W. A. Severance (*Corrosion*, 1958, **14**, Oct., 459t–462t) Properties of a variety of reinforced plastics and their behaviour in various conditions which govern their application are considered. Results of some corrosion resistance tests are given.—D. L. C. P.

Water main protection (*Corros. Prev.*, 1958, **5**, Oct., 63–64) A description is given of the protection of a new water main by wrapping it with Denso tape, after smearing with Denso paste. This is a petroleum-base compound with inert siliceous fillers and passivating additives.

A new type of corrosion protection P. Payer (*Paliva*, 1958, **38**, (10), 339–343) [In Czech] A new corrosion protecting material applicable to steel tubes *in situ* has been developed, tested and put into production in Czechoslovakia, and is now also being manufactured and used in the USSR. The material is superior to the asphaltic type of protection, and to such protective materials as 'Denso', 'Isoplast', PVC, etc. The insulation consists of wrapper-tape having a glass fabric base 2, 4 or 8 in. wide, covered on both sides by an antibacterial mixture of paraffins. It has good passivating properties. Details of the development and mode of application, as well as of the degree of corrosion protection afforded are discussed.

Chemical plant protection by epoxide resin based coating systems J. Rogers (*Corros. Prev.*, 1958, **5**, June, 53–61) The main classification of epoxide-based coating systems are distinguished, and applications to the lining of

chemical plant vessels, pipelines, etc. and to the treatment of chemical plant buildings are described by means of examples.

Epoxide enamels for protection against chemical attack P. J. Gay (*Corros. Prev.*, 1958, **5**, June, 75–79) The general problem of industrial corrosion protection, and the choice and application of epoxide enamels are discussed.

Factors in the production of iron castings likely to cause superficial enamelling defects A. Bordes (*Metalen*, 1958, **13**, Dec. 15, 412–417) [In Dutch] This instalment of the article deals with the numerous components of the base material (C, Si, P, Mn, S, etc. including trace elements) and their influence on the success or otherwise of the enamelling operation. The make-up of the furnace charge and the smelting process are discussed. Reference is also made to the action of enamelled and rusty scrap, also the presence of hydrogen and moisture in the furnace charge.—F. R. H.

Heat-resistant enamels V. Z. Gurevich (*Vestnik Mashin.*, 1958, (12), 61) Enamel No. 9 prepared on a base of silicon-organic compounds binder with addition of Al powder affords reliable protection for metals between 400 and 450°. The process of production and the chemical composition are given.

Influence of the metal on blister formation in powder enamelling of thin cast-iron objects P. Debouté and R. Piva (*Fonderie*, 1958, April, 175–178) Experimental findings seem to prove that cast iron, before enamelling, contains a certain amount of oxygen which inhibits blister formation. This hypothesis is based on the following considerations: Below 680° there can be oxidation of the iron matrix in the presence of free carbon, but above this temperature, graphite is preferentially oxidized in the presence of oxygen or oxidizing agents. During powder enamelling it is the matrix and the graphite which are oxidized in the furnace by the atmospheric and occluded oxygen. When the objects are removed from the furnace and dusted with enamel the oxydation continues at the metal-enamel boundary in the absence of the atmosphere. As the temperature is above 680° it is the graphite which is oxidized at the expense of the iron oxides and of oxygen with considerable formation of gases which pass into the enamel as bubbles. But if during the operation there is sufficient free oxygen in the iron, in the presence of graphite the latter will use it preferentially for oxidation instead of iron oxide or of the oxygen contained in the enamel. Carbon monoxide will form but as it has the same volume as the oxygen used up there will be no gaseous penetration into the enamel.

Influence of iron oxides on the properties of boron-containing and boron-free ground enamels G. I. Belyaev and N. F. Smakota (*Zhurn. Prikład. Khim.*, 1958, **31**, (12), 1792–1799) The plasticity of a borate base is lowered and the viscosity improved by increasing the iron oxide content to 10% and in the case of a boron-free base up to 3%. A further increase of iron oxides in the frits lowers the viscosity and increases the plasticity of enamel melts. Borate enamel shows lower surface tensions and wets the oxidized steel much better. An increase in iron oxides decreases the thermal coefficient of expansion of borate and boron-free ground enamels.

Use of titanium dioxide in self-opacifying glazes K. H. Styhr and M. D. Beals (*Amer. Ceram. Soc. Bull.*, 1958, **37**, Nov., 480–485) White opaque glazes may be obtained by the crystallization of TiO_2 from a clear glass during firing. The compositional range and temperature conditions required are given.—A. G.

Contribution to the study of glazes for zircon porcelains D. A.-Estrada and C. Sánchez Conde (*Rev. Ciencia Apl.*, 1958, **12**, Sept.–Oct., 420–425) The preparation and thermal and electrical properties of a series of glazes suitable for commercial Zr silicate porcelains are investigated.

Non-metallic coatings for corrosion protection W. N. B. Armstrong (*Can. Min. Met. Bull.*, 1958, **51**, Nov., 719–720) A lecture. Paints and plastics are referred to.

Lead based paints in corrosion control N. J. Read (*Corros. Prev.*, 1958, **5**, Sept., 61–67) The use of red lead and calcium plumbate as pigments and their influence in corrosion control are discussed.

Ships' paints' faults H. Courtney Bryson (*Corros. Prev.*, 1958, **5**, July, 47–52) Factors affecting the selection and application of anti-fouling and anti-corrosion paints for ships' hulls are discussed.

New bituminous anti-corrosion paints P. Colomb (*Zaštita Mat.*, 1958, **6**, (7–8), 331–332) [In Serbocroat] The scope and functions of bituminous coatings applied to metals are outlined.—P. F.

Practical experience with zinc-dust paints with respect to their corrosion resistance H. Sagel (*Werks. Korr.*, 1959, **10**, Feb., 66–70) The author reviews critically the merits of paints based on Zn dust and the reasons for the frequent disappointments with these paints in protection. Recommendations for correct composition, corrosion testing, the preparation of the steel surface and painting techniques are made.—T. G.

CLAD SHEET AND HARD-FACING

Roll-bonding aluminium tin bearing alloys to steel: A modified technique employing segregated alloy billets P. W. Goad (*J. Australian Inst. Met.*, 1958, **3**, Nov., 260–266) The various methods used for the bonding of bearing alloys to steel are described. The advantage of using segregated alloy billets is that the steel/alloy interface is practically a steel/Al couple that is easily cold-pressure welded and that the Sn will have migrated towards the bearing surface just where it is wanted most.—T. G.

Chromiding and hardening as protective measures against wear L. Rozeanu (*Met. Constr. Masini*, 1958, (10), 879–880) [In Rumanian] Reducing the wear of the cylinder-piston system to the same level as the other parts of the motor, has not yet been reached. The use of a porous chromided layer ensures continuous lubrication, the use of dissimilar metals is also considered. Different hardness for cylinder and for the ring has also failed to give satisfactory results. Some Rumanian motor works have adopted the principle of chromided rings and hardened linings and this seems to give promising results.—L. H.

Production of two-layer steel for industrial shears E. I. Astrov, A. I. Chichkanov, and Yu. D. Kalmykov (*Stal.*, 1958, *Steel melting processes supplement*, 225–235) A method of pouring molten alloy steel into a mould, (which already contains the ingot), so as to cover it on all four sides, and alternatively on three sides only, has been worked out. Experimental findings show that this method ensures good adhesion of the layers and gives high efficiency characteristics for the finished product.—L. H.

On the rolling textures of cladding metals I. Gokyu and T. Kamijo (*Nippon Kinzoku*, 1958, **22**, Mar., 148–150) The textures of Al, Cu and brass clad on iron sheets were examined by X-ray methods after 90% reduction, and the orientations are given. The textures conform with those of the cold-rolled massive metals.—K. E. J.

Experiences with weld-surfacing of rolls in the Třinex steelworks V. Jung (*Hutnik*, 1958, **8**, (9), 302–307) [In Czech] The technology and economics of the weld surfacing method are discussed. Details are given of a newly developed electrode, the use of which has led to significant increases in the life of surfaced rolls, compared with rolls surfaced with older types of electrodes. Automatic weld-surfacing was used.—P. F.

An investigation of the causes of the appearance of cracks in locomotive wheel tyres after hand surfacing of worn areas with U-340-PB electrodes F. S. Vol'fovskaya, E. Z. Voskoboinik, and Ya. N. Garkavi (*Avtom. Svarka*, 1958, **11**, (9), 93–98) Experimental surfacing which had been carried out on four sets of locomotive wheel sets to make good localized wear proved unsuccessful. Cracking of the tyres is attributed to a series of factors, *inter alia* uneven cooling of the metal during the surfacing process, creating localized stresses; phase changes taking place over various time periods, connected with inhomogeneity of the deposited metal; and the formation of thermally hardened structures, likewise causing stresses. A thorough investigation was therefore made of the stresses set up in the process and metallographic analysis of the structures was carried out. The fundamental cause of the failure was found to be an excessive Mn content (2·70–2·94%) of the deposited metal by comparison with the base metal (1·64%). The Si content was also too high and the C content too low.—M. T.

Increasing the resistance to wear of carburized chromium coatings V. I. Arkharov and V. N. Konev (*Vestnik Mashin.*, 1955, (11), 55–57) Specimens of Armco iron and 18KhNMA and KhG steels had their surfaces ground and electroplated in a bath of 150 g CrO_3 and 1·5 g H_2SO_4 per litre of water, current density 35 amp/dem² at 50° for 3 h. Under such conditions a bright layer of chromium 45–50 microns thick was obtained. The carburizing was carried out in a vertical tubular electric furnace in a mixture of petrol vapours and hydrogen passing through the furnace at a rate of 6 litre per min. Four variants were tested. Findings show that chromiding increases the physical and mechanical properties. The optimum carburizing temperature is found to lie between 950° and 1 050°. The layers show a resistance to oxidation at high temperatures and also a high resistance to acids.—L. H.

Methods of increasing the life of plough shares J. Škrinár (*Zváranie*, 1958, **7**, (9–10), 300–303) [In Slovak] A strengthening of the cutting edges by weld surfacing or surface hardening is recommended, and shown to lead to substantial potential economies.—P. F.

The relining of concrete mixers by hard facing J. W. Shedden (*Welder*, 1958, **27**, Oct.–Dec., 82–89) An illustrated account.

POWDER METALLURGY

High strength prealloyed steel powders (*Powder Met. Quart.*, 1958, (1), 6) Gear production and the properties of the parts produced are briefly noted.

Granulation and form of powder particles obtained by atomization A. F. Silaev and V. I. Prosvirin (*Vestnik Mashin.*, 1955, (6), 61–64) The size of the granules depends on the condition of the atomizing stream of the molten metal and to some extent on the properties of the metal. In the experiments described, the rate of discharge from the crucible did not exceed 0·064 m/sec. It was found that by increasing the difference between the speed of air and of metal the quantity of fine particles is increased.—L. H.

The elastic deformation of metal powder during pressing W. Rutkowski (*Neue Hütte*, 1959, **4**, Feb., 110–113) A series of experiments, carried out on various ferrous and non-ferrous powders, has shown that change in dimensions of the compact after removal of pressure varies considerably with the applied pressure. The dependence of these changes on grain size and hardness is discussed.

Powder has high strength (*Steel*, 1958, **143**, Oct. 13, 106) An iron powder alloy containing small quantities of Ni and Mo is described which can be fabricated to develop tensile strengths of 60 000 psi as sintered and 100 000 psi when heat-treated.—A. G.

For the widest variety of industrial jobs use powder metallurgy gears (*Powder Met. Quart.*, 1958, (1), pp.3).

Infiltration for high strength (*Powder Met. Quart.*, 1958, (1), 7) A table of mechanical properties of infiltrated iron powder parts with 0–0·25, 0·25–0·60 and 0·60–1·0%C is given.

Designing sintered parts G. R. Bell (*Drawing Board and Technical Design*, 1958, **2**, Mar., 2–8) A review of pressing and sintering and the behaviour of metal powders followed by a detailed discussion of factors in the design of small parts securing even compression of all sections and successful expulsion from the die as well as the avoidance of excessive pressures and of their walls, feather edges, etc. which would rapidly give way. **Part II** (*Technical Design and Materials*, **2**, June, 13–15) Advantages in manufacture and the elimination of machining and improvement of tolerances are noted. The mechanics of pressing are considered. **Part III** (July, 6–9) The question of

tolerances is carried further and more intricate designs are reviewed. **Part IV** (Oct., 6–10) The available materials are surveyed and a number of case histories of the redesign of small parts for powder metallurgy are given. **Part V** (1959, Jan., 16–21) Tool and punch design is discussed and taper sections are suggested. Machining is briefly considered and the question of the numbers necessary for economic production is taken up. **Part VI** (1959, Feb., 10–13) Properties of non-ferrous compacts are given.

Furnace sintering of metals and ceramics – II R. L. Harper (*Indust. Heat.*, 1958, **25,** Dec., 2446–2454) The author deals with: Sintering stainless steel powders, Mo and Ta carbides, powder rolled products, as well as with non-ferrous metals and ceramics.—T. G.

Heat-treated powder-iron parts N. Kothari (*Mach. Design*, 1958, **30,** Oct. 30, 93–96) A comparison of iron, iron–graphite and iron–copper–graphite test specimens is made and the effects of various heat treatments were determined including carburizing and carbonitriding. Uneven density makes reproducibility difficult and so must be avoided with special care.

Exothermic and purified exothermic atmospheres for sintering powder metal parts. H. M. Webber (*Ind. Heat.*, 1958, **25,** Oct., 2 000–2 008, 2 012) The production and properties of exothermic and purified exothermic gas atmospheres are described, together with their respective fields of application.—A. G.

Iron–copper–graphite porous antifriction alloys V. E. Mikryukov and N. Z. Pozdnyak (*Vestnik Mashin.*, 1956, (2), 52–57) The specimens were prepared from fine iron powders obtained by reduction of iron scale in a gas generator atmosphere with subsequent reduction for 2 h in a H_2 atmosphere at 800°. Electrolytic copper powder with dendritic and fibrous particle structure reduced for 45 min in a H_2 atmosphere at 400° was the alloy element and the graphite was of commercial quality. Specimens of various compositions were tested. The sintering *in vacuo* gave best results and the optimum composition was found to be that of alloys with 1·6%C and from 5 to 20%Cu.

FERRITES, CERMETS AND CARBIDES

Relations between disaccommodation and magnetic properties of manganese-ferrous ferrite U. Enz (*Lab. NV Philips' Gloeilamp. Separaat*, (1958), No.2628; *Physica*, 1958, **24,** July, 609–624 reprint).

Ferrimagnetic iron oxide compounds with hexagonal crystal structures G. H. Jonker (*Lab. NV Philips' Gloeilamp. Separaat*, (1958), No.2608, *XVI Congres Internat. Chimie Pure et Appliquée, Paris* 1957, *Section de Chim. Minerale*, 1958, 117–123).

Magnetic structure and vacancy distribution in γ-Fe_2O_3 by neutron diffraction G. A. Ferguson jun. and M. Hass (*Phys. Rev.*, 1958, **112,** Nov. 15, 1 130–1 131).

Cermets from thermite reactions J. D. Walton jun. and N. E. Poulos (*J. Amer. Ceram. Soc.*, 1959, **42,** Jan., 40–49) The production of cermets of Al_2O_3 in the reduced metal, with addition of a control agent and also of $ZnSi_2$ and TiB_2 is described. The advantages of the method: (low cost, low ignition and high reaction temperatures, elimination of controlled atmosphere) are set out.

Production of Hoybide cemented carbides (*Machinery*, 1959, **94,** Feb. 11, 307–310) Production in a high-vacuum furnace is described, with an illustrated account of the equipment used.

PROPERTIES AND TESTING

Study of the heterogeneity of metals subjected to tensile tests W. Truszkowski (*Rev. Mét.*, 1958, **55,** Aug., 716–723) It is shown that the coefficient of homogeneity S is influenced by impurities in grain boundaries and dispersed in the metal, and by grain size. A formula is derived for calculating the coefficient, and the method can be used for obtaining the coefficient of uniform elongation A_g of an ideal homogeneous metal. The materials tested were copper, Monel metal and a 0·55%C plain carbon steel.

A large mechanical installation for duration tests L. Baes and Y. Verwilst (*Proc. Soc. Expt. Stress Anal.*, 1958, **16,** 39–56) An installation for testing large structures either statically or dynamically at AIB, Auderghem, near Brussels is described in detail. The machine consists of a loading unit and a separate frame so that it can be built around the specimen on a reinforced concrete floor with built-in anchor points.

A review of parametric methods of estimating the long-term strength of heat-resistant alloys L. Ya. Liberman (*Zavods. Lab.*, 1958, (12), 1 501–1 509) The method propounded by Larson and Muller (*Trans. ASME*, 1951, 74) follows from Arrhenius's equation for the rate of reaction and is therefore based on constants A and Q (activation energy), but as these constants depend on structure and temperature this method is not always operative. This was confirmed by La Rocca (*Jet Propulsion*, 1957, **27,** (6)) also by Nisbet and Hibbard (*J. Metal. Trans.*, 1954, 5). The article reviews the work of further investigators on this subject and gives 16 American and German references.

Determination of the ultimate resistance of spring steel in the presence of contact stresses A. F. Buinov, V. P. Braichev, I. G. Parkhilovskii, and D. A. Sveshnikov (*Vestnik Mashin.*, 1955, (12), 51–55) A method for testing is described which best simulates actual conditions. The principle consists in testing the strength under simultaneous bending and friction and a suitable arrangement of specimens is suggested.—L. H.

The long-term strength of cylindrical bodies weakened by apertures A. A. Zakharov and Sh. N. Kats (*Teploenergetika*, 1958, (6), 52–55) The results are given of an experimental investigation of the long-term strength of cylindrical bodies weakened by apertures, carried out on specimens of austenitic, 1KH18-N9T steel and carbon steel at 700° and 500°C respectively, and these reults are compared with the calculated figures.—M. T.

Investigating the effect of superheated steam on the long-term strength of austenitic steels E. A. Davidovskaya and L. P. Kestel' (*Metallov. Obra. Met.*, 1958, (8), 29–33) Specimens of EI257 steel (approx. 0·11%C, 14·5%Cr, 14%Ni, 2·3%W, 0·4%Mo) which were previously quenched in water from 1 150° were subjected to long-term tensile tests at 600–800°. Chemically pure superheated steam does not lower the long-term strength of these steels, but salt deposits may affect it. It is therefore recommended that the steam in industrial undertakings be purified from salt admixtures.—L. H.

Recent Soviet literature on strength–temperature relation R. W. Guard, W. R. Hibbard jun, and R E. Hoffman (*J. Met.*, 1958, **10,** Nov., 727–730) A review is presented of a number of Soviet papers on theories of strengthening, the relation of strength to bond forces and diffusion, theories of high-temperature strength, and the relation of high temperature strength to phase diagrams.—A. G.

Studies of alloy white cast iron: Effect of Cr% upon the TTT curves and annealed hardness of alloy cast iron I. Fukumoto (*Nippon Kinzoku*, 1958, **22,** July, 351–355) The effect of up to 2·5%Cr on the shape of the *TTT* curve and the annealed hardness of a sand-cast Ni-Cr white iron is described.—A. G.

Plasticity and brittleness of structural steel from data on eccentric stressing of notched specimens V. A. Bykov (*Zavods. Lab.*, 1958, (9), 1 116–1 119) The experiments were carried out on three different conditions of failure, in relation to the safety factor: plastic failure, yield point failure and brittle failure. Under conditions of a small limiting load and small stress accumulation, brittle failure originates from small effects. The plastic shallow fissures under least favourable conditions of repeated deformation are the cause of the simultaneous spreading of brittle cracks under very small limiting loads.

Electron-microscope studies on steel fractures C.-G. Nestler and F. W. Günther (*Arch. Eisenhüt.*, 1959, **30,** March, 161–167) Results are reported of electron microscope studies on fractures at room temperature in specimens of steel C75 W3 with 0·8%C. The results confirmed those obtained by W. Pitsch, J. Plateau, G. Henry, and C. Crussard. In addition, a relationship was found to exist between the density of segregated carbide and the type of fracture.—L. J. L.

Mechanical properties of austenitic stainless steel wires: On the yielding phenomenon T. Watanabe (*Nippon Kinzoku*, 1958, **22,** Mar., 120–123) In cold-drawn wires annealed at 250° or 350°C, negative (compressive) residual strains appeared when a stress below the yield point was applied and then removed. This phenomenon is explained in terms of dislocation theory.—E. E. J.

The influence of minor elements on the isothermal embrittlement of steels W. Steven and K. Balajiva (*JISI*, 1959, **193,** Oct., 141–147) [This issue]

A contribution to the problem of the influence of the so-called 'f'-fracture on the mechanical properties of large forgings V. Koudela (*Hutn. Listy*, 1958, **13,** (8), 687–691) 'f'-fracture is the term provisionally used to denote a type of fracture observed in tensile test specimens from large Cr–Ni–Mo, medium-C duplex steel forgings, which appeared as small, round, bright and shiny, crystalline spots, which normally did not exceed 1 mm in size against a background of dull, tough material. This fracture was accompanied by a fall in the reduction in area to an almost brittle type of fracture of the specimen. From research it is apparent that the bright spots on the fractures are connected with unusual dark-grey inclusions of an elongated formation lying between these areas. The inclusions are small and are not visible to the naked eye on etched or fractured surfaces. At the point where these round spots occur, fracture takes place without deformation of the material. Research is not complete, but it seems that the chief cause of 'f'-fracture is H_2 associated with the inclusion. In the present work a study is made of the influence of this fracture on the mechanical properties of the material, and statistical analysis was made of tests on 372 specimens divided between those with 'f'-fractures and those without. The mean values are compared, and the various mechanical properties correlated. The formulae evolved by correlation allow the values for reduction in area, elongation and notch impact strength to be assessed in relation to tensile strength at a given probability factor, and are of practical use in the control of production methods. The harmful nature of the fracture is clearly shown by the drop in the reduction in area by 29% and the elongation by 27%. It was established that such fractures occur primarily where the degree of deformation is small, and only rarely at high deformations. Statistical investigation indicates that the same relationship also exists for the rates of deformation.—M. T.

Investigation by bending of forgings for special purposes I. G. Generson (*Vestnik Mashin.*, 1958, (12), 35–37) In the Soviet Union, special turbine parts (shafts, discs and other important units) are tested by bending as well as by other tests for tensile and impact strength, reduction of area, and relative elongation. The question arises whether the bending test is useful. In view of experiments conducted over long periods conclusions are reached that this test should be eliminated as it has been in the Western world. The journal invites its specialist readers to participate in this discussion and to send in their views.

Mechanical properties of instrument steels Ya. B. Fridman and V. P. Konoplenko (*Metallov. Obra. Met.*, 1958, (12), 2–9) Investigations of the mechanical properties of four types of steel are detailed. It was found that under bending loads the high strength characteristics of R9 steel are greater than under tensile loads, but under both tensile and bending loads the failure of instrument steels occurs without macro-plastic deformation within the elastic region.

Surface fracture markings on alpha-iron crystals C. F. Tipper, D. I. Dagg, and O. C. Wells (*JISI*, 1959, **193,** Oct., 133–141) [This issue]

The use of the hot torsion test for determining the forgeability of steel G. Wallquist and J. C. Carlen (*Jernkont. Ann.*, 1959, **143,** (1), 1–28) The forgeability is defined as the maximum deformation possible without permanent damage and the torsion test was examined as an indication of this. A special machine was built and tests were made on 12 steels. Number of twists to fracture, torque and torsional work were studied as functions of composition, temperature and rate of twisting over the range 700–1 250°C and 10–200 rev/min. The number of twists to fracture rose to a max. with temperature. The max. value was found in the austenite range, varying with composition, and the number of twists was lowered by increased rate of twisting. The work to fracture varies similarly with temperature and increases with speed of twisting. Neither torque nor work to fracture is a suitable index of forgeability but number of twists to fracture, preferably at ~30°C below the temperature at which this is a max., is a fair indication of plasticity.

Some considerations relating to the investigation by intentional fracture of iron and steelmaking products R. Borione (*Centre Doc. Sidér. Circ.*, 1959, (1), 201–206) The examination of deliberately fractured specimens to estimate grain size, determine the transitional temperature of fracture and to investigate physical defects and inclusions is discussed.

The influence of ferrite banding on the impact properties of mild steel W. S. Owen, M. Cohen, and B. L. Averbach (*Ship Structure Committee Project SR-136, 4th Report: SSC-114* 1958, Oct. 6, pp.23) Charpy properties were compared for a severely banded ferrite-pearlite and a randomly distributed specimen. Both types were prepared from the same steel by homogenizing treatment of an initially banded material. Some observations on banding were made. At the lower end of the temperature range Charpy values were not affected by banding, direction of axis or notch orientation. At higher temperatures the random structure shows higher energy absorption and impact value depends greatly on orientation of specimen and notch. No preferred crystallographic orientation for ferrite was found.

A magnetic specimen mount for fractography D. B. Ballard and J. A. Bennett (*Met. Prog.*, 1958, **74,** Nov., 114–115) A specimen mount which can control the orientation of samples for microscopical and other examinations is described. The 'specimen' magnet is held against the inside of a transparent plastic hemisphere by an external 'control' magnet. By sliding the latter over the hemisphere and twisting it, the position of the sample, which is attached to the free end of the inside magnet can be adjusted at will.—D. L. C. F.

Comparison of notched bar tests over the temperature transition range A. W. Johnston (*Materialprüf*, 1959, **1,** Jan. 20, 13–18) The relationship between the energies absorbed by Izod Charpy U-notch and Charpy V-notch test-pieces have been investigated for three mild steels and three alloy steels, and the temperature-energy transition curves have been established.—A. G.

Estimating the quality of sheet steel by means of tests for impact resistance V. G. Chernashkin, A. M. Gofner, and M. A. Sivryukova (*Zavods. Lab.*, 1958, (9), 1112–1115) Comparative tests have shown that specimens with a 5 mm notch can serve very well for estimating the quality of steel, because, from the nature of the curves obtained, it is possible to estimate the grain size and the condition of the metal. Tests with varying widths of specimens, corresponding to the thicknesses of metal, cannot, however, be recommended, because the data obtained for impact strength are not comparable.—L. H.

On the inertia of the dynamometer of the hydraulic testing machine L. T. Timoshuk and V. S. Zoteev (*Zavods. Lab.*, 1959, (1), 109–112) When a load is applied to the specimen under test by pendulum dynamometer, fluctuations occur on applying the load and in the determination of yield strength, which are conditioned by the changes in the rate of loading and by the inertia of the pendulum. The use of an electro-tensometer is suggested and recordings of the dynamometer of the machine are compared with oscillographs, showing appreciable differences.

Effect of heat treatment on the variations of the temperature-dependence curve of the impact strength of steel V. K. Tselikov (*Metallov. Obra. Met.*, 1958, (10), 17–22) Measurements are reported of the impact strength of approx. 0·1%C, 3·5%Ni, 0–1%Cr steels in the range − 200 to + 30°C after various heat treatments involving heating above A_{c3}, cold-rolling and ageing.—L. H.

Heat resistant properties of complex alloyed ferrite A. M. Borzdyka and A. V. Merlina (*Metallov. Obra. Met.*, 1958, (12), 10–16) This material has high mechanical properties at 500–550° and at room temperature. Addition of 0·4%Nb to this Cr–Mo–W steel further increases its resistance to creep and its long-term resistance, but reduces impact strength at normal temperature and also plasticity (elongation and reduction of area) in long-time tensile tests at high temperatures.

Change in strength coefficient due to martensite formation in plastic deformation M. G. Gaidukov and V. D. Sadovskii (*Metallov. Obra. Met.*, 1958, (5), 4–8) Strain hardening in austenitic steels where plastic deformation is accompanied by martensite formation has been examined in low-C, 16–29%Ni alloys. Specimens were cut from square bars rolled to different extents and true stress-strain diagrams were constructed. The extent of conversion depends on the relative values of the deformation temperature and Ms point. Discontinuous yielding occurs associated with martensite formation and two load maxima appear.

The Belgian contribution to the study of the Swift cup-forming test P. E. Lagasse and L. Lilet (**International Deep Drawing Research Group*, 1958, Dec., pp.7) A new precision machine has been constructed and tests on 20 steels are reported. The device operates on sheet of thickness 0·6–1·2 mm and with certain precautions the test is reproducible and gives values which do not correlate with other physical properties. The test is very sensitive to thickness but not at all to surface condition or to natural ageing after temper rolling. Suggestions for further improvements are made.

On the accuracy of the Erichsen test B. Otta and J. Teindl (*Sbornik, Ostrava*, 1958, **4,** (2), 121–124) [In Czech] It is shown that the dispersion of values obtained in Erichsen cupping tests with samples from a given sheet depends upon the quality of the steel as well as upon the mode of rolling of the sheet. With killed steels the dispersion is small.—P. F.

The deep-drawing properties of sheet steel L. A. Rubenkova (*Vestnik Mashin.*, 1958, **38,** (10), 49–52) A review is given of a theoretical analysis of the testing methods and an experimental investigation of the drawing properties of sheet steel, aimed at the development of methods of assessing the behaviour of steel during drawing, undertaken at the Russian Academy of Sciences. Research shows that the decisive influence on the behaviour of the metal is exerted by the stressed state arising during stamping. The present paper deals with monoaxial and biaxial stresses but not with the complex state of stresses arising from the simultaneous action of tensile, bending and compression stresses. A comparison is made between experimental and calculated data. The effect of friction is also considered.—M. T.

Residual stresses and strength of teeth in cemented gears D. S. Elenevskii (*Vestnik Mashin.*, 1958, (9), 10–13) The influence of the residual stresses on the fatigue resistance of these teeth was assessed by the wear of the tips of cogs ground after hardening. The quantitative determination of the effect of residual stresses on the surface of the cogs was measured on a hydraulic pulse machine. Results show that the fatigue limit for carefully ground teeth was 15 000 cycles, but when ground at an increased speed it was reduced to 8 500 cycles. When these teeth were then shot peened the fatigue-resistance increased to 12 000 cycles.

On the hypothesis of the strength of metallic materials according to H. M. Schnadt A. Krisch (*Arch. Eisenhüt.*, 1959, **30,** March, 169–185) H. M. Schnadt devised a diagram giving the conditions of multi-axial stresses and deformations. His work is critically examined in considerable detail, and it is maintained that major portions of Schnadt's 'strength diagram' are not susceptible to experimental proof.

Plastic flow defects of metal in parts forged with a die C. Gazdaru (*Met. Constr. Masin.*, 1958, (8), 659–663) [In Rumanian] Various parts are analysed and investigated as, for example, ball bearings, connecting rods, the fork of a universal joint axle and the crown gear of a tractor differential. Suggestions are made for the elimination of these defects during manufacture, based on the physical laws of flow.—L. H.

Calculating the anisotropy of the properties of metals during (mechanical) treatment V. F. Sgibnev (*Vestnik. Mashin.*, 1958, (12), 33–34) Tests were carried out on sheets of 300 and 900 mm width and 1 920 mm length, of a thickness between 0·8 and 1 mm made of 08VG steel, Al and two other alloys. Control meshes 50 and 100 mm square were drawn on the surface of the sheets which were then subjected to tensile loads for deformation in stages of between 10 and 12%. The findings showed that it was not the ratio of the measurements that influenced deformation, as maintained by Davidenkov and Vasiliev (*Zavod. Lab.*, 1952, 5), but the anisotropy of the properties of the material.

Effect of the conditions of cold deformation and heat treatment on the fine structure of EI428 steel (Sichromal) E. Yu. Chemadurova (*Metallov. Obra. Met.*, 1958, (10), 36–40) An X-ray investigation is reported on the structure of EI428 steel (0·08%C, 1·55%Si, 5·96%Cr, 0·84%Al) with elongation of 30%, reduction of area 60%, and impact strength of 0·5 kg/cm². The steel was quenched from 900–1 050°, tempered at 800° and in some cases preheated to 180° before rolling. Lattice parameters, block dimensions and hardness figures are listed.—L. H.

1957 references on fatigue (*ASTM publication*, 1958, pp.63) There are eight references on each page in alphabetical order of authors.

Materials testing by high-frequency electromagnetic pulsators A. Ténot (*Rev. Gén. Méc.*, 1959, **43,** Jan., 21–24) A description of the use of three types of high-frequency electromagnetic pulsator for fatigue testing.

The historical development of research on the fatigue of materials and structures J. Y. Mann (*J. Australian Inst. Met.*, 1958, **3,** Nov., 222–241) A review marking the hundredth anniversary of Wöhler's first published work on fatigue (148 references).—T. G.

Fatigue properties of high strength steels H. E. Frankel, J. A. Bennett, and W. A. Pennington (*Trans. ASM*, 1958, **52,** preprint 121, pp.23) Four steels with 0·44–1·06%C in a number of quenched and tempered conditions heat-treated after final finishing to remove surface structure changes were tested in fatigue. Fatigue strength was lowered by retained austenite up to ~10%, apparently due to transformation during stressing.

Research on austenitic Cr-Mn-C-N stainless steels Hsiao Chi-Mei (*Acta Met. Sin.*, 1958, **3,** (2), 138–180) The systematic study of over 200 experimental types of Cr-Mn-C-N steel have been studied by a combination of microscopical examination, X-ray diffraction, electrolytic extraction, chemical analysis, hardness and magnetic measurements, density and dilatometric methods, oxidation tests, tensile tests at room and at high temperatures, creep-rupture rests, etc. and the findings are presented under the headings: Stable austenitic region; solid state reactions, martensite transformation, precipitation reactions and formation of sigma-phase, properties at room and elevated temperatures; effect of interstitial solid solution; effect of precipitation on strength at high temperatures; effect of V, W, Mo, Nb, B and Si and tentative recommendations for industrial application.

Molybdenum steels F. J. Mariñas (*Met. Elect.*, 1959, **23,** Jan., 144–145, 147, 149, 151–153, 155, 157–158) A description is given of the properties of Mo, Cr–Mo, Ni–Mo and Ni–Cr–Mo steels.

The use of 1% chromium, 0·17% nickel, 0·001% boron steel for making large parts A. P. Ermolenko and N. I. Konstantinov (*Stal'*, 1959, (1), 85–87) The heat-treatment and mechanical properties of this steel containing Ti are described for making large parts and compared with those of B-free steels.

An economical austenitic heat-resisting steel of the MnCr(Ti)-17·7 type; its physical and mechanical properties F. Poboril and P. Jehlička (*Zvár. Sbornik*, 1958, **7,** (1), 86–96) [In Czech] The development of a substitute steel, which consists above 200°C essentially only of austenite and titanium carbide, is described. It is shown that up to 620°C it is economically advantageous to use this steel rather than stainless Cr or Cr–Ni steels; its heat-resisting properties are but a little inferior to the former.—F. F.

An experiment in the use of steel alloyed with aluminium N. P. Zab'yalov (*Lit. Proizv.*, 1958, (10), 30) To replace expensive and complex alloys, the hearth of an electric furnace was cast in low alloy steel alloyed with Al of the following composition: 0·8%C; 0·6%Mn; 0·29%Si; 0·038%P; 0·027%S; 1·95%Al. The mechanical properties of the casting were: compression strength 48–49 kg/mm^2 and depth of curvature 2·5 mm (at 300 mm between the supports); hardness 167H_B. The fracture of the steel had a coarse crystalline structure, which consisted of alloyed ferrite and coarse dark acicular crystals of a Fe–Al compound. The hearth was in operation for ten months in a furnace operating at 900–930°C. On removal because of distortion, it showed no evidence of cracking, and the degree of surface oxidization and scaling was minimal.—M. T.

Aircraft quality steels: medium and low-alloy type L. F. Barnhardt and P. Adams (*AIMME Electr. Furn. Steel Proc.*, 1957, 142–147) Properties, especially temper brittleness susceptibility, gas and non-metallic solid inclusions, and particularly melting practice are outlined, and magnetic particle testing is referred to. **Carburizing bearing steels** W. Spicer (148–149). The 3310–12 grades are considered and melting practice is briefly indicated. **52100 bearing steels** A. K. Blough A brief account of requirements in melting.

METALLOGRAPHY

Effect of zirconium on the austenitic grain-size in iron and steel A. Adachi, K. Mizukawa, H. Omoto, and N. Hiraoka (*Tetsu to Hagane*, 1958, **44,** Oct., 1193–1197) Electrolytic Fe and low-C rimmed steel melted in N_2, A or *in vacuo* was used in a study of the effects of Zr on austenitic grain refining. It was found that Zr in combination with N_2 or C, but not with O_2, causes grain refinement. This was pronounced in electrolytic Fe, but was concealed in the mild steel owing to impurities. The results are presented in graphs and tables having English captions.—T. G.

The problem of grain size in cast iron H. Morrogh (*Brit. Found.*, 1958, **51,** Nov., 588–591) Lack of knowledge of the matrix grain size of various types of cast iron is probably due to the predominating influence of graphite structure on the properties of the iron. Various aspects of cast iron grain size are discussed, and the relation between graphite structure and 'eutectic cell' size is treated in more detail.

The measurement and effect of grain size in steel castings N. J. Jackson (*Brit. Found.*, 1958, **51,** Nov., 584–588) A review of the literature shows that the simplest and probably the most reliable method of revealing austenitic grain size is the martensitic etch method, but the significance of grain size in relation to the engineering properties of castings is not fully understood (19 references).

Cooling transformation diagrams for AISI 4815 and 43BV 14 R. C. Hess and E. Kozic (*Metal Progress*, 1958, **74,** Nov., 96B).

Temporary changes in mechanical properties [of steel] during phase transformations V. G. Vorob'ev (*Metallov. Obra. Met.*, 1958, (3), 35–38) Studies on steels and non-ferrous alloys are reviewed and work is reported on the increase of plasticity accompanying fall of tensile strength during austenite-to-martensite transformations at temperatures below zero where the diffusion mechanism suggested by Bochvar could not operate. As the effect is present a bond-weakening process is envisaged lasting for a very short time but showing a great increase in plasticity.

The influence of aluminium on the microstructure of lamellar and SG irons T. Dumitrescu, M. Solacolu-Nicolaid, and A. Kathrein (*Studii si Cercetari de Metalurgie*, 1958, (4), 417–438) Experimental findings of the simultaneous influence of Al, Si and Mg on the graphitization and microstructure of irons have shown among others, that graphitization appears in SG irons with a 11% Al content, but only in specimens of decreasing cross-section (18 mm cross-section for 0·46% Al and 3 mm for 11% Al). The graphitization increases with Al up to 3% and thereafter diminishes. The explanation proposed is that supercooling, characteristic of Mg- treated irons plays an important role in graphitization and that the inhibitory influence of Al is due to its reducing the intensity of the cooling process.

Comparative study of the allotropic transformations of iron and uranium P. Lehr and J. P. Langeron (*Symposium de Métallurgie Spéciale*, 1957, June, 47–56) [In French] Mainly on U. The existence of a plastic deformation accompanying allotropic transformations in iron under thermal cycling is, however, discussed and tests on Armco iron are described.

Investigations of dilatometric curves. Plotting derived curves and determining transformation points A. Clere (*Centre Doc. Sidér. Circ.*, 1959, (1), 207–211) Dilatometric curves were plotted for several steels, and the derived curve obtained; application to the determination of the A_{C_1} point is discussed.

The role of the surface in the graphitization of iron alloys Ya. V. Grechnyi and I. G. Kheifets (*Lit. Proizv.*, 1958, (12), 14–17) It has been shown experimentally that the number of graphite nuclei appearing in steel enclosed in a cover of iron free from Cr differs little from the number forming in a non-insulated specimen. It has also been shown that the inhibiting effect of an external layer of Cr-iron on graphitization is not connected with the stresses which occur in the heating and annealing of the two-layer specimens. The explanation of the inhibition of the graphitization in two-layered specimens is therefore that it is due to a decrease in the rate of diffusion of vacancies. Experimental conclusions point to the important role played by the surface of the specimen as a source of the vacancies necessary for the graphitization of iron-carbon alloys.

New aspects of autoradiographic investigations of alloy structures S. Bercu, A. Kathrein, N. Petrescu, and C. Rizescu (*Studii si Cercetari de Metalurgie*, 1958, **3,** (3), 371–383) The possibility of extending the method used for the study of microsegregations to the microscopic details of alloy element distribution is indicated, and the use of statistical methods, it is shown, may be replaced by exact knowledge of the properties and compositions of micro-volumes of the material.

An investigation of the titanium–iron–carbon system. I. On the titanium–iron system. II Y. Murakami, H. Kimura, and Y. Nishimura (*Nippon Kinzoku*, 1957, **21,** Nov., 665–669; 669–673) I. The solid solubility range of Ti Fe is 52–54 wt-%Fe; the solubility curves are nearly vertical against falling temperature, and the lattice parameter decreases with increase in iron concentration. For $TiFe_2$ the range is 68·5–77 wt-% Fe at about 1300°C, and narrows with fall in temperature; the lattice parameters fall with increase in iron content. II. In the ternary system the following phases exist: α and β-Ti-rich solid solutions, graphite, δ-(titanium carbide) phase, TiFe, $TiFe_2$ and α- and γ-Fe-rich solid solution. No ternary compound is detected. The ranges of these phases, and two quasi-binary eutectic reactions are explained. **III** (Dec., 712–716) The general outline of the constitutional diagram is given. There are two quasi-binary eutectic reactions, viz. liquid $\rightleftharpoons \delta + TiFe_2$ and liquid $\rightleftharpoons \delta + (Fe)\alpha$; equilibrium relationships are therefore considered for the regions TiC–Fe–C, TiC–Fe–$TiFe_2$ and TiC–$TiFe_2$–Ti. In the second region there is a ternary eutectic: liquid $\rightleftharpoons TiFe_2 + (TiC) + (Fe)\alpha$.—K. E. J.

CORROSION

Processes of electrochemical corrosion G. V. Akimov (*Corrosion*, 1958, **14,** Oct., 463t–483t) This is the translation of a chapter of the Russian book 'Theory and Research Methods of Metallic Corrosion'. Considerable data are reported in 54 figures and 6 tables. Overvoltage is discussed in detail. Use is made of the Evans diagram for real processes. Considerable attention is given to the factors affecting the rate of oxygen diffusion to the metal. The theory of microcells is examined and a review made of some of the experimental data for processes with hydrogen depolarization. The effect of alloying elements on corrosion rates of metals in various media is discussed.—D. L. C. P.

Corrosion – here and there F. W. Ernhardt (*Ind. Eng. Chem.*, 1958, **50,** Nov., 71A–72A) Corrosion and stress-corrosion in chemical plants are exemplified.

Corrosion in water engineering A. W. Neal (*Corros. Prev.*, 1958, **5,** Oct., 46–48) Types of corrosion met with in water supply pipes and containers are outlined, and measures used to prevent or reduce corrosion are enumerated.

Corrosion in railway engineering – (I) H. Johns (*Corros. Prev.*, 1958, **5,** Oct., 51–52) The problem of corrosion in railway vehicles, its causes and treatment are discussed.

Corrosion in civil engineering R. J. Salter (*Corros. Prev.*, 1958, **5,** Oct., 53–55) Problems met with due to the corrosion of steel and timber structures, particularly in sea water are outlined, and methods of protection are described briefly.

The corrosion resistance of ductile iron F. L. LaQue (*Corrosion*, 1958, **14,** Oct., 485t–492t) The corrosion resistance of ordinary ductile iron is compared with that of other irons and steel, and this property is considered in relation to the internal structure of the metals. Corrosion data in various environments are presented and explained. It is concluded that in general, ductile iron has satisfactory corrosion resisting properties which permit its use where grey iron, malleable iron or steel are employed.—D. L. C. P.

A study of the solution rate of iron in liquid bismuth from a number of ferritic steels L. W. Graham and G. W. Wilson (*JISI*, 1959, **193,** Oct., 103–106 [This issue]

Current research on corrosion and tuberculation of cast iron T. E. Larson and R. V. Skold (*J. Amer. Water Works Assoc.*, 1958, **50,** Nov., 1429–1432) Effects of mineral content were studied with reference to loss in carrying capacity due to tuberculation. A special test chamber is described. Freshly cast unground interior pipe surfaces were found to be very resistant to corrosion. The black phase between metal and grey phase was found to be magnetite, the grey phase consisted of monoclinic pyroxenes ($CaSiO_3$, $FeSiO_3$) and polyhedron garnets such as $Ca_3Al_2(SiO_4)_2$ or $Fe_3Al_2(SiO_4)_2$.

Corrosive influences peculiar to sewage A. G. Arend (*Corros. Prev.*, 1958, **5,** Aug., 41–42) The importance of determining small concentrations of oxygen in assessing the factors influencing corrosion in pipelines, etc. carrying sewage is discussed, and the Lindner–Wirth hydrogenation–phosphine method for determining accurately very low concentrations of oxygen in organic materials is described.

Behaviour of carbon and stainless steels in acid waters R. J. Schmitt (*Corrosion*, 1958, **14,** Oct., 445-t) An example is cited of the improved life of condenser tubes in a wash-oil regenerating system using water at pH 4·5. This was effected by changing from carbon steel to 18–8, Cr–Ni tubes. Lower alloy tubes are sometimes effective.—D. L. C. P.

Boiler corrosion and its alleviation by feed water conditioning – (2) A. Laird and N. Reast (*Corros. Prev.*, 1958, **5,** May, 57–62) The sources of boiler feed water are described, and methods of boiler feed water treatment are discussed under the headings of external softening and internal treatment. The required specifications of treated water are listed, and

reference is made to the control of caustic cracking.

Regarding corrosion of stainless steels at places of contact with non-metallic materials I. B. Ulanovskii and Yu. M. Korovin (*Zhur. Priklad. Khim.*, 1958, **31**, (9), 1366–1370) The specimens investigated were of 1 Kh13 steel, rubber, Plexiglass and Textolite, and the medium was Black Sea water. The experiments were carried out in large glass containers of 6 to 20 litres. The damage appears to be concentrated, a characteristic of galvanic pairs. Around the contact zone a friable hydroxide deposition of alkaline anodic products is distributed. In the galvanic process with Black Sea water, an increase in the cathode surface causes intensification of the damage. This occurs along the boundaries and then spreads beyond, gradually covering the whole surface of the contact area. The influence of the pH on the electrode potentials has been investigated and it was found that one of the main causes of damage under these conditions was the activation of the surface because of a drop in the pH of the electrolyte in the clearance space at the contact zone.

Some data on the resistance to intercrystalline corrosion of pure austenitic steels containing 23% chromium and 23–28% nickel. Yu. I. Kazennov and L. P. Kolosova (*Avtom. Svarka*, 1957, (2), 11–21) The influence of welding heat on resistance to intercrystalline corrosion of three steels is investigated and methods of increasing this resistance in the non-stabilized EI 533 steel are suggested. The experimental data are listed for each type of steel.

Corrosion of stainless and carbon steels under cathode polarization in nitric acid solutions N. D. Tomashov, M. M. Kurtenov, and E. N. Mirolyubov (*Zhur. Fiz. Khim.*, 1958, **32**, (4), 904–908) Corrosion experiments on 1Kh18N11B and three other steels under cathodic polarization in a 3% HNO_3 solution have shown the possibility of destroying the passivity (totally or partially) and of the subsequent appearance of cathodic electrochemical protective coatings on stainless and carbon steels in nitric acid solutions. The dependence of the corrosion rate of 1Kh18N11B stainless steel under cathodic polarization is similar to that of carbon steels without a cathode potential.

Records related to a natural gas distribution corrosion control programme L. C. Hill (*Corrosion*, 1958, **14**, Oct., 451t–454t).

Some basic features of the corrosion of metals by higher fatty acids K. Gardelka (*Sbornik, Ostrava*, 1958, **4**, (3), 269–276) [In Czech] The gradual weight loss of samples of Zn, Cu, Al, brass, duralumin, iron and stainless steel in pure oleic and stearic acids, in linseed oil, as well as in air and *in vacuo*, was studied at 25 and 72 C. The rate of corrosion was higher at 72 than at 25 C in all cases.

High-temperature corrosion of refinery equipment by sulphur compounds W. G. Richards (*Werks. Korr.*, 1959, **10**, Feb., 74–77) The author discusses the corrosion of steels by H_2S above 500°F and reports on tests of stabilized 18–8 steels for intercrystalline and stress corrosion.—T. G.

The early history of cathodic protection in the United States – Some recollections R. J. Kuhn (*Corros. Prev.*, 1958, **5**, April, 46, 72) A description by the author, who was responsible for many initial cathodic protection installations in USA, of some early projects with which he was associated.

Corrosion resistance of welded joints in 1Kh18N9T steel under conditions of nitric acid production B. I. Medovar, N. A. Langer, L. E. Vesker, K. Kotsev, and M. Ganev (*Avtom. Svarka*, 1958, **11**, (9), 61–73) The results are given of corrosion resistance tests under normal production conditions in a nitric acid plant carried out on submerged arc welded joints in 1Kh18N9T (18%Cr–9%Ni tube steel). Welds made with electrodes of similar composition or with high Si (1·8%) content evidenced intergranular corrosion of 0·2–0·3 mm/year. But using electrodes which were additionally alloyed with either 0·99%V or 0·62%V + 0·56%Nb and a high Si content (1·4 and 1·2% respectively) the welds had improved resistance to intergranular corrosion whether in the as-welded state, heat-treated (650°C for 2 h; cooled in air) or cold-worked. Intergranular corrosion is more likely to occur on the axial face of the weld, as a result of localized C segregation and reduction of the ferrite content in this area than in the peripheral areas. Cold-working considerably improved the corrosion resistance of the welds. Satisfactory results were also obtained from laboratory tests in copper sulphate solutions and nitrate solutions of sodium fluoride.—M. T.

Cathodic protection of a gas distribution system E. F. Fowler (*Corrosion*, 1958, **14**, Nov., 533t–538t) The manner in which a gas company applies cathodic protection to its gas distribution system is described. Topics discussed include setting up a basis for current requirements, analysing of cathodic protection work-orders, protection for new installations and replacements of pipe, and cathodic protection of a town as a unit. Details are given, with examples, of installations and work forms.—D. L. C. P.

Corrosion protection for pipe type electric transmission lines in the Chicago area W. T. Rose (*Corrosion*, 1958, **14**, Oct., 493t–494t) The method of protecting pipe-type high voltage transmission lines is described. The pipes are coated and cathodically protected by Mg anodes and a rectifier. Special problems of the application are dealt with.—D. L. C. P.

More revenue from longer lasting water meters through corrosion control (*Corrosion*, 1958, **14**, Oct., 108–114) Corrective measures employed to counter plugging and galvanic corrosion of domestic and commercial water meters are described. Steps included replacing dissimilar metal parts in meters, and coating parts with a low viscosity oil-base coating containing inhibitors.—D. L. C. P.

Hull corrosion prevention system (*Corros. Prev.*, 1958, **5**, July, 53–54) The use of an adapted lead alloy anode for the cathodic protection of ships' hulls is described.

The protection of double bottom tanks K. G. C. Berkeley (*Corros. Prev.*, 1958, **5**, July, 43–46) Trials are described showing the success obtained by the cathodic protection of ships' double bottom compartments, using Mg anodes.

ANALYSIS

Thermographic quantitative analysis of Kerchensk iron ore V. V. Gusev (*Ukrain. Khim. Zhurn.*, 1958, **24**, (1) 103–106) The specimens consisted of ores passed through a 0·25 mm mesh before being subjected to thermal analysis under constant conditions. A weighed quantity of 2 g at a rate of heating of 12°/mn with a resistance of 181 000 ohms in the circuit was used. Results obtained compared with chemical analysis show an average error $< 1·5$% and the time required for this method of analysis is between $2\frac{1}{2}$ to 3 h.

Rapid methods of analysis for metallurgical products H. Bastius (*Neue Hütte*, 1959, **4**, March, 178–181) Methods are reported for the rapid determination of SiO_2, Se, Fe, and Al in slags; of Cu, Pb, and Zn in slags, and of Sn and Ge. A description is also given of a mechanical instrument for liquid–liquid separation and of two types of automatic ion-exchange columns.

A sampling method of specimens for analysis of gases in iron and steel T. Nishiyama and H. Shigematsu (*Nippon Kinzoku*, 1958, **22**, March, 136–140) The segregation of gases (O_2, H_2, N_2) and the relationship of microstructure to gas content was studied for specimens cast in moulds of different sizes and compositions.—K. E. J.

Study on the method of taking a sample for determination of oxygen in molten steel S. Maekawa and Y. Nakagawa (*Tetsu to Hagane*, 1958, **44**, July, 754–761) A simple vacuum method of taking a sample of steel direct from the furnace is described. For acid OH steel, the results for oxygen content agree with the bomb method, but are lower than the casting method; for basic OH steel they are lower than those from the bomb, suction and casting methods (15 references).—K. E. J.

Problems concerning the content and determination of nitrogen, hydrogen and oxygen in cast iron L. I. Levi (*Lit. Proizv.*, 1958, (11), 20–23) Gaseous elements, nitrogen, oxygen and hydrogen can be present in solid and liquid cast iron in various forms. Their influence is often either over or under-estimated. This is mainly due to the imperfection of methods used for their determination. The most accurate method is the melting of metal in a high vacuum. This method was used by the author and his co-workers in their tests, carried out on a considerable scale. A few types of cast iron of different chemical composition and obtained by different methods were used. The influence of temperature, which varied from 1 180–1 910°C, was investigated. It was found that the greater part of the gases was evolved at 1 180–1 300°C, but an appreciable amount was still obtained at 1 340–1 380°C; the maximum of evolution for different gases occurs at different temperatures. The content of gases in samples made from the same sample of metal can vary considerably. It is therefore recommended that at least three parallel tests should be carried out.—S. S.

Sampling and analysis of electric furnace steels for nitrogen content R. H. Colin and G. H. Snelling (*AIMME Elect. Furn. Steel Conf. Proc.*, 1957, 21–26) A review of current methods. It is considered that N_2 distribution in the bath is sensibly uniform. **The sampling and analyses of nitrogen in electric furnace steels: Review and evaluation of vacuum fusion methods** W. A. Peifer (27–37) The method is described and a diagram of the apparatus is given. Typical results are shown. **Comparison of methods on duplicate furnace samples** A. F. Gross (35–37) A sampling method was devised and analyses on stainless steels showed great concordance except for a 5%Cr–0·5%Mo steel when examined in three laboratories. **Analyses of steel for nitrogen and its compounds** H. F. Beeghly (37–44) Choice of method in relation to type of steel and purpose of the data is discussed. Physical methods and reaction with B and Si and the effects of Al and heat treatment on the nitrides formed are considered.

On the determination of the various forms of iron in rocks Yu. P. Trusov (*Zhurn. Anal. Khim.*, 1959, (1), 139–140) Fe^{++} is titrated with $KMnO_4$ after decomposition of the rock by HF + H_2SO_4. Pyrites remains unchanged and is filtered off. Fe^{++} and Fe^{+++} are determined in the filtrate with $Hg_2(NO_3)_2$. The pyrite is then ignited and fused with $K_2S_2O_7$ and the iron in it titrated with $Hg_2(NO_3)_2$ after dissolving the melt.

Amperometric determination of iron in various materials with Trilon B Yu. I. Usatenko and M. A. Vitkina (*Zavods. Lab.*, 1958 (9), 1058–1059) It has been established that Trilon B oxidizes, with a rotating platinum microanode, in alkaline or acid solutions. The corresponding volt-amp curves show sharp diffusion waves the height of which is proportional to the concentration of Trilon B. The horizontal sections of the curves are produced between 0·8–1·0V and between 0·45–0·65V. This renders it possible to determine many metals combining with Trilon B to form complexes. Tests with specimens of known composition have shown a remarkable agreement with analytical findings.—L. B.

SiO_2, Al_2O_3, V_2O_5, and Cr_2O_3. (Study of the chemical analysis of sand iron and ilmenite – II) S. Wakamatsu (*Tetsu to Hagane*, 1958, **44**, Nov., 1288–1293) The author describes a simple spectrophotmetric method for the determination of SiO_2, Al_2O_3, V_2O_5, and Cr_2O_3.—T. G.

The analysis of nickel sulphamate plating solutions G. H. Bush and D. G. Higgs (*Trans. Inst. Met. Finishing*, 1958/59, **36**, Winter, 43–47) Methods for determining total N_2, free ammonia, Ni, boric acid and naphthalene-1 : 3 : 6-trisulphonic acid in sulphamate solutions are described. Typical results on synthetic mixtures are reported.—A. G.

The application of the spectrograph to foundry practice E. Humphries (*Castings*, 1958, **4**, Oct., 15, 17, 19) Routine analyses are outlined.

Possibility of analysing steel for alloying elements in electric furnaces without taking samples V. N. Balandin and S. L. Mandel'shtam (*Zavods. Lab.*, 1957, **23**, 545–548) The furnace arc is used as a spectrographic source and relative line intensities are measured and the source (metal or slag) of the vapours present are examined. Reproducibility was

satisfactory and extension to the OH furnace is suggested.

Flame photometry in the analysis of raw materials and steel products C. B. Belcher (*BHP Techn. Bull.*, 1958, **2**, Sept., 26–28) The principles and techniques of flame photometry are described briefly, and some typical applications are enumerated.

Vacuum spectroscopy gives rapid steel analysis C. L. Winchester (*J. Met.*, 1958, **10**, Nov., 735–737) A description is given of the Quantovac, a vacuum spectrograph for the rapid analysis of iron and steel for all important elements including carbon, phosphorus and sulphur.—A. G.

Simultaneous determination by spectral analysis of carbon and other impurities in steels and irons A. S. Dem'yanchuk (*Avtom. Svarka*, 1958, (9), 41–45) A method is described for quantitative spectrographic analysis of simple carbon and low-alloy steels and irons by determining simultaneously the carbon and other impurities with one exposure by means of high frequency discharges as a source of excitation of the spectrum. The time of analysis is shortened owing to the simultaneous determination, and the accuracy of the results is claimed to be completely satisfactory.—L. H.

The rapid spectrometric analysis of gases in steel W. Koch, S. Eckhard, and F. Stricker (*Arch. Eisenhüt.*, 1959, **30**, March, 137–144) A method for the direct spectrometric determination of CO, N_2 and H_2 is described. The gases are excited in a high-frequency field; the intensity of emission bands during aspiration of the gases is traced. The intensity maximum reflects excitation; in gas mixtures, maximum intensity is proportional to the concentration of the gases in the mixture.—L. J. L.

Some special features of the spectrographic analysis of phosphorus in steel and welded joints E. S. Kudelya (*Avtom. Svarka*, 1958, **11**, (9), 88–92) Special features of the egress of P from a steel specimen into a radiant discharge cloud are considered in the light of experiments on steel containing radioactive P. The permanent electrode during analysis should be of a material with a low affinity for oxygen, in order not to impoverish the surrounding air in oxygen. Graphite and carbon electrodes were found most suitable; 3–5 mm rods should be ground off into a hemisphere and 6–10 mm rods sharpened to a tip with a working surface 2–3 mm in diameter. The line Pl 2149.11 Å was found to be the most suitable, using the iron line 2145.2 Å for comparison, at currents of 12–14 A. The mean relative error in the measure of the P content, starting with concentrations of 0·006–0·008%, was ±3–7%. Analysis can be made on metal only 0·02–0·003 mm thick, and the dia. of the area examined was normally 3 mm.—M. T.

Spectrographic analysis of binary iron and chromium alloys E. V. Lifshits, V. G. Konovalov, and V. F. Erko (*Zavods. Lab.*, 1958, (12), 1483–1484) Alloys containing between 0·1 and 30% Cr in iron and between 0·1 and 1%Fe in Cr were investigated in the form of massive specimens and of thin films up to 20μ thickness, also the distribution of Cr in the surface layer up to a depth of 750μ. The method consists in dissolving the specimens and electrolysing the solutions with the porous hollow anode suggested by C. Feldman (*Anal. Chem.*, 1949, **21**, 1041). Precision ± 6%.

Comparative assessment of various methods of spectrographic determination of nickel in steel E. I. Brainin (*Zavods. Lab.*, 1958, (12), 1479–1483) Six methods are compared for examining specimens containing 0·2 to 4·8% nickel. Three methods with spark excitation of the spectrum and three in which the light source was the arc are described. Comparative results are tabulated.

Fluorescent X-ray spectrographic analysis E. M. Anger and J. P. Martin jun. (*AIMME Elect. Furn. Steel Proc.*, 1957, 165–174) Determination of Ni, Cr, Mn, Mo, Nb and W with a Norelco spectrograph is described and compared with chemical analyses. **Standardization and the use of the Spectromet in a steel foundry** C. L. Richards and H. Levesque (175–180) Analyses showing the reproducibility for Ni, Mn, Si, Mo, Cu, Cr and V in various alloy steels and Ni-resist iron are shown. **The Quantovac – a direct-reading instrument for the control of carbon, phosphorus, sulphur and other important elements in iron and steel** H. W. Calkins and M. F. Hasler (181–190).

Rapid spectrophotometric determination of lead in leaded free-cutting steel with dithizone K. Ota and S. Mori (*Nippon Kinzoku*, 1958, **22**, June, 290–292) A simple method of masking iron with hydroxylamine–KCN prior to the determination of lead with dithizone is described. The purification of dithizone is also dealt with.—A. G.

Determination of impurities in ferroniobium by spectrographic analysis A. B. Shavich, Ya. M. Kalinskii, N. I. Chabanenko, and M. A. Perepelkina (*Zavods. Lab.*, 1958, (12), 1478–1479) The method consists in analysing powder specimens and standards prepared by successive dilutions; for example, by dilution of a standard of Fe–Nb with iron oxide and spectrally pure graphite in such ratios as 1 : 2 : 3, 1 : 3 : 4, 1 : 4 : 5, etc. The specimens for analysis are also diluted in the same proportions with the same components. The apparatus and the source of excitation are standard and line pairs for various elements are given.

New instruments for investigation and the determination of calorific value of gases and for the control of furnace installations W. Eickler (**Gas Wärme*, 1957, **6**, Nov., 348–351) Portable gas analysis apparatus is reviewed. The Kalorex apparatus for calorific value, the Barex-S for oxygen in low concentration and an improved Orsat apparatus still being developed are described. The Combustrex apparatus for measuring flue draught, pressure and temperature, and CO_2 content is included.

INDUSTRIAL USES AND APPLICATIONS

Metallic constructional materials for the chemical and allied industries S. Rowden (*Eng. Digest*, 1958, **19**, Nov., 473–476) Factors affecting the choice of a structural metal for the chemical industry are discussed – i.e. resistance to corrosion under operating conditions, weldability, etc.

Steel for railway purposes J. Dearden and J. E. Roberts (*Inst. Locomotive Eng.*, 1958/59, **48**, (3), 357–387, discussion 387–410) The types of steel and their properties and uses for railway purposes, including Diesel engines, with notes on performance, failures in service (statistical) and numbers of cycles of loading endured by various components are given.

Present boiler designs at the Taganrog boiler works M. V. Meiklyar (*Energetik*, 1958, **6**, (10), 3–8) Descriptions with drawings are given of various boilers for steam temperatures up to 570°C and pressures of 100 atm with an output of up to 640 t/h, spray steam coolers, primary and secondary superheaters (radiation type), natural gas/oil fired and cyclone combustion chamber boilers, currently produced for electricity stations. The steels used for their construction are discussed.—M. T.

Heat-resisting steels for steam turbines R. Pokorný (*Zvár. Sbornik*, 1958, **7**, (1), 52–60) [In Czech] A survey of the development of the use of turbine steels, and of researches in the past few years is made, with special reference to advances in Czechoslovakia. Czechoslovak researches on Cr–Mo, Cr–W, Cr–W–V, and Cr–Mo–W–V are reviewed, and the choice of suitable steels for given applications in this field is discussed. Ferritic-pearlitic steels are believed to have a long future ahead of them.

Reconditioning worn cylinder linings by replaceable steel bands V. I. Kazartsev and N. I. Sobolev (*Vestnik Mashin.*, 1956, (3), 61–66) U8A, U10A and 70S2KhA steels are recommended for cylinder linings. Formulae are given for determining the thickness of the linings in relation to the diameter of the cylinders, and the operation of stripping the cylinders and fitting the new linings is explained in detail.—L. H.

Steel in prestressed concrete W. O. Everling (*Blast Furn. Steel Plant*, 1958, **46**, July, 691–697) A review of the properties of steel used in prestressed concrete construction is presented. In addition to discussing the tensile condition of service, stress corrosion and the effect of temperature are considered.—B. G. B.

The endless belt (*Swedish Foreign Commerce*, 1958, (6), 42–44, 51) Uses of the steel conveyor belts made by Sandviken steel works are illustrated and discussed.

MISCELLANEOUS

Metal savings in metallurgy. II J. Luca (*Met. Constr. Masini*, 1958, (9), 791–795; (10), 885–889) [In Rumanian] This is a study of all the sections of the industry where these losses of metal occur, and suggestions are offered for their elimination. It includes all departments from the smelting to the finished products.

Some topical problems concering steel savings (*Met. Constr. Masini*, 1958, (10), 890–891) [In Rumanian] In the process of production, various stages are analysed where savings can effectively be obtained as, for example, reduction of the limits of tolerance, delivery of sections according to their theoretical weights, introducing light sections, etc.—L. H.

Vibration phenomena in turbogenerators with steel foundations. Part III K. Schäff and K. H. Krieb (*VDIZ*, 1959, **101**, Feb., 117–124) A theoretical and experimental investigation is described into the vibration characteristics of turbogenerators mounted on steel foundations, and methods of controlling the vibration are suggested (16 references).

Antiferromagnetic properties of the iron group trifluorides E. O. Wollan, H. R. Child, W. C. Koehler, and M. K. Wilkinson (*Phys. Rev.*, 1958, **112**, Nov. 15, 1132–1136).

Preliminary studies in chlorinating titaniferous slags from Idaho ilmenite M. M. Barr, H. L. Gilbert, and D. D. Harper (*US Bur. Mines Rep. Investig.* 5431, 1958, pp.14).

BOOK NOTICES

AMERICAN WELDING SOCIETY. '*Welding Handbook*'. Part II. Welding Processes: Gas, Arc and Resistance, 4th edn. 9 × 6 in., pp. vi + 13 chapters [not continuously paginated] + Index. Illustrated. 1959, London: Cleaver-Hume Press Ltd. (Price £3 12*s*.)

The Handbook published by the American Welding Society has long been recognized as one of the most comprehensive publications available on welding technology. The continued and rapid advances which have been made in welding, however, have necessitated the almost complete re-writing of the Handbook since the 3rd edition was published in 1950 and in view of the complexity of the task it was decided, by the Society, to issue the fourth edition in five parts. Part I, dealing with Basic Principles and Data, was reviewed in this *Journal* for July 1958, p. 295 and the issue of Part II has been awaited with interest. This second section of the new Welding Handbook deals with welding processes and includes chapters on gas-welding, metal-arc welding and spot and resistance welding. Each chapter has been compiled by a panel of experts and, consequently, the welding processes are described with a wealth of authoritative detail. It should not be thought, however, that such detail is superfluous; each chapter is a meticulous treatise on the welding process considered and is designed to give the reader a complete and accurate picture of the techniques involved without attempting to evaluate the merits of a particular process for specific applications. Comprehensive chapters are included on the latest inert-gas-shielded-arc processes and the sections dealing with the resistance welding processes are excellent. The book, however, is not a general handbook of hints and tips for the practical welder; it is a comprehensive treatise which can be thoroughly recommended to the welding engineer or others seeking up-to-date information on the technical aspects of welding processes. The book, of course, does not deal with the metallurgical aspects of welding since these are covered thoroughly in Part I.

In the review of Part I it was remarked that, as far as basic concepts are concerned, the British Welding Industry does not lag behind its American counterpart. While Part II fully reflects the great advances that

have been made in the United States in recent years in the development of welding processes it is interesting to note that the book does not induce the feeling of inferiority or frustration in the British reader that it might have done a few years ago. One gains the impression that the gap which existed between the standard of welding practice and technology in this country and in America has finally been bridged and that the best technological practice in this country will bear scrutiny by even the most critical of our American cousins.

As might be expected of a publication issued by a body having the standing of the American Welding Society the book is well arranged and illustrated, is clearly printed on good paper and is well bound. By present-day standards it is good value for money.—W. I. PUMPHREY.

BARDIN, I. P. '*Anwendung von Sauerstoff bei der Stahlerzeugung*'. [Translation from the Russian. '*Proizvodstvo Stali s Primeneniem Kisloroda*', 1956.] 8 × 5¾ in., pp. 344. Illustrated. 1959, Berlin: VEB Verlag Technik. (Price DM. 30.)

Originally published in Moscow in 1956 as 'Production of Steel with the Use of Oxygen', a title which more truly reflects its contents, this compilation should not be regarded as a textbook for there is lacking a progressive theme. The seventeen 'chapters' are by different authors, and this leads to some duplication. The absence of an index makes it difficult to refer readily to any particular aspect. The book must therefore be read in its entirety but if this is done, there emerges a clear picture of the fundamental studies and practical trials which have led to optimum output rates. It will also be clear how the staff of the central research institutes have worked in close co-operation with the plant operatives and how fruitful such collaboration can be.

The first two chapters are merely introductory and historical. The next ten chapters relate essentially to the development work carried out at Zaporozhstal up to 1956 and, although the open-hearth furnaces there are fired with mixed gas, there are undoubtedly many lessons that could be applied to practice in liquid fuel-fired units. All aspects of oxygen usage are covered. Details will be found of how optimum methods of adding oxygen for enrichment of combustion air and for lancing for carbon removal have been studied by model techniques, calculation, and works' trials. The problems of fume production and effect on refractory life have been solved by similar methods. It is the model studies where criticism might be levelled at the methods used to simulate furnace conditions of gas flow, gas composition and dust content and the explanation of the mechanism of wear of basic roofs appears too simple.

Particularly interesting is the attention paid to the co-ordination of degree of oxygen enrichment, fuel rate, charging rate, ore feed, and roof and checker temperatures, to obtain maximum benefit to production. If it is said that the standard practice evolved specifies fuel rates; oxygen enrichment during charging, melting and *refining*; scrap charging and ore feeding times; oxygen flows during lancing for decarburization, and that the reasons for these are clearly explained, this probably indicates as succinctly as possible the interest that this book will have for the steelmaker and fuel engineer.

Other chapters deal with the distribution of sulphur between metal and slag and loss to waste gases, as assessed by radio-isotope studies, the chemical, metallurgical and mechanical properties of rimming steel produced by the new methods, limited experiments for the production of steel from stahleisen and a medium phosphorus high chromium iron and the use of oxygen in electric arc furnaces. The last chapter is a very brief description of the tonnage oxygen plant at Zaporozhe, with an output of 380000 cu.ft per hour, or approximately 360 tons per day. Metallurgists who encounter Soviet specification codes will be interested in the appendix which gives the chemical compositions of fifteen specified steels.

This book describes what happened in 1956; but what is happening now? Perhaps the rapidly developing exchange of information will provide an answer.—J. PEARSON

BOWMAN, E. H., and FETTER, R. E. '*Analyses of Industrial Operations*'. 9 × 6 in., pp. viii + 485. Illustrated. 1959, Richard D. Irwin Inc.: Homewood, Ill., (Price $7.95.)

A collection of articles from British and American journals which provides an interesting set of case studies of quantitative methods for the analysis of industrial operating problems. The material has, in large part, been used as a graduate course in the School of Industrial Management at the Massachusetts Institute of Technology. It is divided into five main parts:

Applications of Linear Programming; Other Programming Applications; Waiting Line Applications (which includes a paper by Brisby and Eddison previously published in *JISI*, October 1952); Applications on Incremental Analysis; Total Cost and Value Models.

An important feature of value for teaching and study is an editorial preface to each paper summarizing it and emphasizing points of special interest.

BUNSHAH, R. F. (Editor). '*Vacuum Metallurgy*'. 9 × 6 in., pp. xviii + 472. Illustrated. 1958, New York, London: Reinhold Publishing Corp.; Chapman & Hall Ltd. (Price £5.)

This book is the first of a series on Materials Technology and is compiled from a series of lectures given at a course on Vacuum Metallurgy at the New York University College of Engineering. Contributions are included by American, West European and Soviet authors. The object of the course was to provide a rapid familiarisation for the engineer with vacuum metallurgy, to embrace making, shaping and treating of metals and alloys under vacuum, and the evaluation and utilization of the products.

The volume is divided into ten sections, the first of which deals with the selection of pumping systems, leak detection and 'trouble shooting'. The application of thermodynamics and kinetics to vacuum metallurgy is treated in general terms in the second section. Three sections are devoted to arc melting, induction melting and electron bombardment melting techniques and this is followed by sections on degassing both in the liquid and solid states, and on distillation of metals. Section VIII is concerned with the metallurgical applications of vacuum processing and chapters are devoted to descriptions of the properties of vacuum-treated steels and high temperature alloys, to the production of refractory metals, nuclear power plant materials, powder metallurgical products and vacuum coatings for metals. The technical matter is concluded by a section in which analytical techniques are discussed. The last chapter is of a more general nature and combines a general survey of some of the more noteworthy developments in the field of vacuum metallurgy with a discussion of future trends. A very useful classified bibliography—extending to about 500 references—is provided in addition to the authors' individual references in their respective chapters. Author and subject indexes are also provided.

The volume, is in general, very well presented. As is inevitable in view of the multiplicity of authors, there is a certain amount of repetition and overlap, both of text and illustrations. This is, however, not undesirable and makes for easy reference besides preserving the integrity of individual sections. A good balance is preserved between practical and academic aspects, and in addition to the fundamental theory in section II more specific theoretical matter has been included at the appropriate points. There are, unfortunately, some printing errors, including a mis-quotation of the formula for Sievert's Law (p. 44) although a lucid textual enunciation is given. This book certainly fulfils the objects quoted in the preface, and is of inestimable value to the metallurgist, and especially to anyone new to the field of vacuum metallurgy.—G. HOYLE.

DURELLI, A. J., *et al.* '*Introduction to the Theoretical and Experimental Analysis of Stress and Strain*'. 9 × 6 in., pp. xxx + 498. Illustrated. 1958, New York, Toronto, London: McGraw Hill Publishing Co. Ltd. (Price £4 17*s*.)

The theoretical analysis with which the book commences deals adequately with the development of the usual equations. Especial care is taken to state the assumptions and limitations involved at each stage. The field is, however, well-trodden and several texts (e.g. Timoshenko, Southwell) are already available. The logic of presenting first and full 3-dimensional theory and then proceeding to the particular by simplification is emphasized in the Preface, but as a consequence some '2-dimensional' chapters only follow their associated '3-dimensional' chapters after a considerable interval. Particularly in the treatment of geometrical representations and applications of the theory the text gives an impression of disjointedness and repetition. In the sections on applications there are rather surprisingly no worked numerical examples and no exercises set other than purely mathematical.

Part II 'Introduction to the use of experimental stress analysis methods', deals with fundamental concepts, statistical methods and dimensional analysis. For experimental work some knowledge of these subjects is necessary and it is convenient to have them outlined. A Bibliography is given for statistical methods and one for dimensional analysis would also have been welcome.

Of the remainder of the book, some three-quarters (140 pages) is devoted to the technique of brittle coatings and, as claimed, the description of this method is more complete than any previously published. There are chapters on the general background, stresses and strains in brittle coatings, the properties of 'Stresscoat', and applications. These are very thoroughly done but such an extended treatment of a special technique seems somewhat out of place in an introductory text. A number of mechanical strain gauges are briefly reviewed in the final chapter; electrical resistance strain gauges, almost indispensable for recording dynamic strains, receive only a passing reference.—D. BUCHANAN.

HUGHES, L. E. C. (General Editor). '*Electronic Engineer's Reference Book*'. 2nd edn. 7¼ × 4¾ in., pp. 1588. Illustrated. 1959, London: Heywood & Co. Ltd. (Price 84*s*.)

As compared with the first edition reviewed *JISI*, September 1958) the second has 350 extra pages of text including some new sections on non-destructive testing, components, radiation detection, digital computer applications, simulators and electronic telephone exchanges. The lists of official bodies, journals and abbreviations have been removed. Like the first edition, the work is an extremely valuable and original compendium on the subject, but owners of the first edition would not find the second a very valuable acquisition.

GRABBE, E. M. S. RAMO and WOOLDRIDGE, D. E. (Editors). '*Handbook of Automation, Computation, and Control*. Vol. I. 9 × 6 in., pp. xx + 26 chapters [not continuously paginated] + Index 20 pp. Illustrated. 1958, New York, London: John Wiley & Sons Inc., Chapman & Hall Ltd. (Price £6 16*s*.)

It is not surprising that, in order to 'gather together in one place the available theory and information on general mathematics, feedback control, computers, data processing and systems design', the editors of this handbook have found it necessary to divide the work into three volumes which, if judged by this one, will run to about 3000 pages. As befits a handbook, the

main results of each branch of the theory considered are quoted without proof, but the provision of extensive references to each chapter (there are over 500 in this volume) allows quick access to the necessary background material if required.

This first volume is entitled Control Fundamentals and is concerned mainly with the underlying theoretical background to both technical and organizational control systems. There are thirteen chapters devoted to general mathematics basic to control theory, such as complex variables and Laplace transforms for particular application to servomechanisms, Boolean algebra for computer design and probability and statistics for operational research. General topics include matrix algebra, differential and integral equations and a comprehensive chapter on numerical analysis. Operational Research techniques for studying the organizational aspects of control by means of mathematical and statistical models are detailed and the main results of these models are quoted. These are followed by a section on information theory which leads *via* the topics of smoothing, filtering and data transmission to that of feedback control which occupies the last eight chapters. These chapters use the nomenclature of the American Standards Association and begin with a clear definition of the symbols used. The analysis, stability, transient and frequency responses and compensation of feedback systems are detailed together with the main effects of noise, random inputs extraneous signals and non-linearity of such systems.

The work is up to date to about 1957 and provides an excellent reference book for all personnel concerned with the design of control systems. Like all handbooks, however, it leaves the impression that, in the fields covered, the work is complete.—R. G. Massey.

Howard, E. D. (Editor). '*Modern Foundry Practice*', 3rd edn. $8\frac{1}{2} \times 5\frac{1}{2}$ in., pp. 464. Illustrated. 1958, London: Odhams Press Ltd. (Price 30*s*.)

Over a period of fifteen years this book has become recognized as a general guide to British foundry practice. It has recently been reprinted for a third time, a fully revised and enlarged edition, to keep pace with progress in the industry. It will continue to be read as a textbook by the student and apprentice and its value is now enhanced by the inclusion of up-to-date matter of interest to the craftsman and foundry executive. It comprises a series of carefully presented, fully illustrated monographs by eighteen specialist contributors. Each chapter is carefully blended and integrated to give a thoroughly clear and straightforward account of the industry, readily understandable by even a beginner. New features in this third edition include spheroidal graphite cast iron, pressure-cast aluminium pattern plates, epoxy-resin patterns, pop-off flasks, recent developments in melting furnaces and sand technology. The CO_2 process and resin bonding for shells and cores are new matters particularly well treated although one fails to find mention of dielectric core hardening methods now becoming popular in the U.S.A. This reviewer has detected no factual aberrations and only one or two inoffensive printer's errors.

Although each chapter is an authoritative individual work, the whole book is uniform in style, a tribute to the editor, Mr E. D. Howard, and the volume comes to the reader well bound, printed and illustrated as one would expect from the publishers. Today, foundry technology is developing so rapidly that a textbook, unless written and published without delay, tends to be out of date before it is off the press. This book, however, does not suffer from this criticism; it will long remain a valuable book of reference, fully worth the price.—D. V. Riley.

Institution of Mechanical Engineers. '*Proceedings of the Conference on Lubrication and Wear. London: 1–3 October 1957*'. $11\frac{1}{2} \times 8\frac{1}{4}$ in., pp. viii + 911. Illustrated 1959, London: The Institution. (Price £8.).

This is a very excellent publication of its class and of considerable metallurgical importance. The papers cover 742 pages, followed by 86 pages of discussion, 26 of written communications and 51 of authors' replies. The numerous plates, which are not listed, are not included in the pagination. Abstracts of all the papers of metallurgical interest will be found in this issue of the *Journal* (under Lubrication, Corrosion, Machining and Machinability, and Properties and Tests) so that in this review more general matters can be considered. The one general criticism that might be made in these days of reflex copying is that although the paper is of high quality and thick for so large a book, it is rather lacking in opacity and the print shows through more than would be expected. Again, the Index is inadequate and badly planned, being too much of a rearranged Table of Contents—this on the test of using it to find topics noted in reading, which proved very difficult. Printing and proof reading are excellent, the only misprint noted was 'phosphorous' on p. 634. The book is classified in 'Sessions' each on some special topic but actually with much overlap and, to assist the reader (not, we hope, to side-track the reviewer) each session is introduced by a paper summarizing the articles that were to be read. These are, in fact, excellent, even the one that apologizes for difficulties due to influenza. This symposium will be quite indispensable to the lubrication engineer, but there is much of interest to workers on corrosion, to mechanical and electrical engineers in general and, of course, to the metallurgist. The high standard of the Institution is so well known that it is only necessary to add that this volume is not unworthy of its sponsors.—J. G. Cockburn.

International Institute of Welding. '*Multilingual Collection of Terms for Welding and Allied Processes*'. $9\frac{1}{2} \times 6\frac{1}{2}$ in. Illustrated. Part I: General Terms—Welding Procedure, Characteristics and Inspection. In twelve languages, 1955, pp. 132. Part II Gas Welding. In ten languages, 1958, pp. 78. Supplement: Serbo-Croat and Slovene terms, 1958, pp. 24. Part III: Arc Welding. In twelve languages, 1958, pp. 140. Bâle: Association Suisse pour la Technique du Soudage. (Price: Part I, 16*s*. 0*d*. Part II, 10*s*. 6*d*. Supplement, 7*s*. 9*d*. Part III, 13*s*. 6*d*. From Joint Committee for International Welding Relations, 54 Prince's Gate, London SW7.)

This valuable multilingual dictionary in twelve languages (Danish, Dutch, English, Finnish, French, German, Italian, Norwegian, Serbo-Croatian, Slovenian, Spanish and Swedish) has much wider application than the Welding Industry. Parts already issued cover General Terms, Procedure, Characteristics and Inspection, and Gas and Arc Welding. Each of the terms is given a number which is the same whatever the language. Under this number the various language terms appear again, illustrated in many cases by drawings. The next section of the Collection will be devoted to Resistance Welding, but it will probably be a couple of years before it appears. Further sections are promised in due course. This moderately priced and excellently produced work is published with the financial assistance of UNESCO. It is a happy exercise in international relations which deserves success and should be extended.—M. L. Pearl.

Kingery, W. D. (Editor). '*Ceramic Fabrication Processes*'. $10\frac{1}{2} \times 8$ in., pp. xi + 235. Illustrated. 1958, New York, London: Technology Press of M.I.T., John Wiley & Sons, Inc., Chapman & Hall Ltd. (Price 76*s*.)

This new volume contains twenty-two papers on the principles and practice of ceramic fabrication, all but one of these being based on lectures delivered at a Special Summer Programme at Massachusetts Institute of Technology in 1956. In selecting this topic the organizers had in mind the very considerable progress that has been made in this field over the past ten to fifteen years and the interest now being taken in ceramics in such fields as atomic energy, rocket propulsion, jet propulsion and electronics which has stimulated research in special ceramics to a marked degree. The authors, who were all specialists, were therefore selected to cover a wide range of interests both academic and industrial and their contributions are authoritative if somewhat uneven in their content. (One suspects the operation of a commercial censorship in at least one case.)

The topics covered are slip casting (five papers), pressure fabrication (four papers), plastic forming (four papers), drying and firing (three papers), special processes (three papers) and ceramic microstructures (two papers) and, although ordinary furnace refractories, which are the life-blood of the iron and steel industry are somewhat neglected (the words chrome-magnesite are not even mentioned) there is no doubt that, in deciding to publish the various lecture in a single volume, the organizers have performed a valuable service to ceramic technology. It will be found particularly useful for the accounts it gives of such processes as hydrostatic moulding, vibratory compaction, sintering and hot pressing and for the overall picture which it provides of the present state of theory in these fields. The two papers on the effects of microstructure on properties, though one of these is concerned primarily with electrical ceramics, deal with an important aspect of ceramics which has until recently been somewhat neglected.—J. White.

Lange, K. '*Gesenkschmieden von Stahl*'. 9×6 in., pp. xii + 379. Illustrated. 1958, Berlin: Springer-Verlag (Price DM. 34.)

Dr Ing. K. Lange, the author of this book, was associated with Professor Dr Ing. O. Kienzle at the Technische Hochschule, Hanover, and much of its contents is based on experimental work and research carried out there.

The book is divided into sections, the first dealing extensively with the fundamental principles of the forming of steel and of those materials available to the Drop Forger. Tables are included giving detailed analysis of various types of steels and attempts are made to indicate their forgeability at various temperatures. In the second section deformation of the metal during the forging operation is considered, the different processes, i.e. forging, upsetting, etc., being described; emphasis being placed on the interim forging operations. The third section of the book concerns itself with the description of plant used in the drop forge, namely, hammers, presses, upsetters, shears, etc., and considers the die-making techniques and heating of the stock prior to forging. A chapter in this section discusses the question of scale formation and its removal. The fourth section is perhaps one of the most important parts of the book, discussing the relation of the shape of a drop forging and its influence on the forging, the material being forged and the final user of the forging, and points out that the matching of all these requirements is the basis of the drop forger's art. The fifth section discusses accuracy and tolerances obtainable, and proceeds to consider the problems of forge layout, throughput, costing, etc.

The book is intended to be both a test book for a student and a handbook for the Drop Forger and the Design Engineer. It contains a most comprehensive bibliography of published work. It is amply illustrated with first-class photographs and diagrams. This book is probably the most complete contribution that has been made to the technique of drop forging and the many allied processes involved. It is hoped that there will be eventual translation and publication in English.—J. H. Jackson.

Marshall, J. D. '*Furness and the Industrial Revolution*'. $8\frac{1}{2} \times 5\frac{1}{2}$ in., pp. xxiii + 438. Illustrated. 1958, Barrow-in-Furness: Central Library and Museum. (Price 23*s*.)

This book provides an essential background to any study of the Furness iron and steel industry and places the phenomenal

growth of the city of Barrow in its proper framework of economic and human events.

The first section of the book gives a factual picture of life and trade in Furness in the century preceding the railways, assembling a large mass of statistics of population, trade and finance in such a way as to provide a convincing support for the conclusions drawn about the development of the area. The account of the charcoal iron industry places the many partnerships and their financial problems in a clear light and gives a welcome account of the exploration and opening up of the many ore fields. There is an excellent study of the charcoal trade.

The Barrow iron and steel industry is detailed in its relation to ore bodies and finance, and the vital part played by the Furness Railway and its later connections, particularly with the Durham coke areas, is clearly demonstrated. It is useful to have a precise account of such a self-contained iron producing area, presented from the viewpoint of the economist, free from any technical detail of processes, or mechanical aspects. Trade, finance and transport are the chief topics, but linked with these are the human topics of housing, health education and local government, which are the essential concomitants of a new and increasing industrial population.

The text is not easy reading but it is frequently lightened by the inclusion of biographical details of the more prominent persons whose activities brought about the eventual establishment of Barrow City and its iron and steel industries. The book brings the story to the end of the nineteenth century and leaves the twentieth century developments for a separate telling.—A. RAISTRICK.

LÜTH, F. '*Planung und Bau von Hüttenwerken*'. Zweite, neubearbeitete Auflage. pp.viii + 187. Illustrated. 1958, Berlin: Springer-Verlag. (Price DM. 28.50.)

The usefulness of this book lies in the fact that it not only provides a check-list of all the various factors which have to be taken into account when planning a new works, but also collects together typical data on such matters as the size, performance and cost of different types of plant which would be of assistance in the planning and building of a new steelworks. Although there is an appreciable quantity of data of this kind available it is scattered among many different journals, and any book which collects such information together is welcome.

Two-thirds of the book is taken up with the problem of planning, starting with the early decisions about the siting of the works, its size, and the products which will be made. Material balances and flows, and the layout of the works are then considered, and this leads on to a comparison of the various alternative processes and plants that can be used for iron and steel making and the mechanical working of steel. It is in this section that most of the revision has taken place in preparing the second edition of the book; not only are performance and output figures brought up-to-date, but the new processes for iron and steel making and continuous casting, which are now coming into prominence, are discussed. Naturally, there are few data on the performance of these new processes, but sufficient indication is usually given to enable their scope to be judged. Consideration of the fuel and power balances, problems of transport and supplies of materials, the provision of services, organization of auxiliary departments, and special problems like standardization and safety measures, complete this major part of the book.

The remaining short sections deal with cost estimating, building and its organization, and commissioning, and the book ends with a number of examples taken from practice. A new example added in the second edition deals with the planning of a steelworks using electric iron and steelmaking processes. Tabular data are plentiful and costs quoted are related to the date so that changes in value can be taken into account; but the reader is warned that figures given in different tables, being drawn from different sources, are not always consistent with one another, and calculations are not always free from arithmetical mistakes. References to the original sources of information are given as footnotes; naturally these are, almost without exception, German sources.—H. R. MILLS.

MERRIMAN, A. D. '*A Dictionary of Metallurgy*'. 11 × 8½ in., pp. 401. Illustrated. 1958, London: Macdonald and Evans Ltd. (Price 126*s*.)

Dr Merriman's dictionary was first published in monthly instalments in *Metal Treatment and Drop Forging*, but since then it has been much revised, some of the additional information coming from readers of that journal. In its present form it contains nearly 7000 definitions, 236 tables, and 290 illustrations. The author's definition of 'metallurgy' itself provides an excellent illustration of the scope of the dictionary; 'the practice and science of extracting metals from their ores, the refining of crude metal, the production of alloys and the study of their constitution, structure and properties, and the relation ship of physical and mechanical properties to thermal and mechanical treatment of metals and alloys'. Within these wide limits the information given is accurate and copious: definitions range from the colloquial (e.g. 'goose-neck') to the scientific (e.g. 'megacycle', 'Paschen's Law', 'secondary electrons'), and the illustrations from the simple—'a pipe chaplet'—to the complex—'S-curve of a 3% nickel steel'. No metallurgist should be without this invaluable reference book.—J. P. SAVILLE.

MILLER, T. R. '*The Monkland Tradition*'. 8½ × 5½ in., pp. xiv + 154. Illustrated. 1958, Edinburgh: Thomas Nelson & Sons Ltd. (Price 18*s*.)

The author's ancestors were amongst the earliest coal and iron masters in the Monkland area of Lanarkshire. Today, his firm is a prominent engineering company concerned, amongst other projects, with the building of atomic plant. This brief and chatty account spans the years between and gives a personal and interesting account of the changes in family and economic history which have taken place.

MINISTRY OF POWER. '*The Efficient Use of Fuel*'. 2nd edn. 9½ × 6 in., pp. viii + 888. Illustrated. 1958, London: Her Majesty's Stationery Office. (Price £1 5*s*.)

The first edition of this book appeared in 1944 prepared, as the editors observe, in an atmosphere of urgency under war-time conditions. Since that time, the science and practice of fuel technology have advanced, but the necessity for their full application has not receded; this country is now, for the first time in its history, an importer of fuel—of oil-fuel, as the iron and steel industry is well aware, but more significantly of solid fuel. The most efficient use of solid and liquid fuels is a national necessity.

The general arrangement of this second edition wisely, therefore, resembles the first, although the opportunity has been taken, in the belief that some knowledge of fuel technology is more widely spread, to modify some of the elementary treatment of the first; other parts have been brought more into line with modern practice and new matter introduced—for instance in the sections dealing with boilers and their auxiliaries and with furnaces. The chapters on heat-transmission and on fluid flow have been entirely rewritten. The book should be most valuable to all industrial users of fuel.—J. P. SAVILLE.

STANFORD, E. G., and FEARON, J. H. (Editors). '*Progress in Non-Destructive Testing*'. Vol. I. 9¾ × 6 in., pp. vii + 267. Illustrated. 1958, London: Heywood & Co. Ltd. (Price 60*s*.)

This book is the first of a series containing critical reviews by specialists on specific aspects of non-destructive testing, and if the very high standard of the present volume is maintained through the series, the editors will have made an invaluable addition to the literature on this subject.

It is made clear in the preface that non-destructive testing covers a much wider field than that of detecting flaws in metallic specimens, and that the subject embraces the study of any parameter of a specimen. Medical diagnosis is probably the oldest known example of N.D.T., and one section of the present book reviews the application of electronics to clinical studies. Other sections cover Ultrasonic Stress Wave Propagation, Industrial Radiography, Neutron Radiography, Thermal Conductivity Measurements, Damping Capacity Measurements and Nuclear Magnetic Resonance.

Considerable emphasis is placed on the fundamental physics behind each application. These theoretical analyses greatly enhance the value of the book, since the use of results quoted to new studies is thereby simplified. The editors and publishers are also to be congratulated on the general presentation. The text is clear and well laid out, with profuse diagrams, and an extensive bibliography to each section.—B. O. SMITH.

RUHFUS, H. '*Wärmbehandlung der Eisenwerkstoffe*'. (Buchreihe 'Stahleisen-Bucher' Band 15.) 9 × 6½ in., pp. xii + 483. Illustrated. 1958, Düsseldorf: Verlag Stahleisen m.b.H. (Price DM. 52.)

This is a well-written book dealing with the heat-treatment of a wide range of ferrous metals from high cobalt permanent magnets to railway lines and including cast irons. Although not reproduced on special art paper, the photomicrographs and diagrams are particularly good.

The book commences with a short introductory chapter dealing with the early history of heat treatment, and in the second chapter the author deals adequately with the structure and the isothermal transformations of iron and iron-carbon alloys. The third chapter is divided into three sections, dealing respectively with the purpose of heat treatment, the influence of the method of manufacture of the material upon its response to heat treatment, and with the preliminary examination of materials to determine their probable response to heat treatment. The fourth chapter deals in considerable detail with many types of heat treatment (including the heat treatment of cast iron), with surface hardening, and with surface treatments with zinc, lead, aluminium and chromium. The apparatus necessary for the heat treatment of small and large parts is dealt with in chapter five which includes not only descriptions of furnaces but also of quenching tanks, hardening machines and testing apparatus. The sixth chapter is one that will be of particular interest to anyone contemplating the installation of a heat treatment department. It deals with the planning and organization of a heat-treatment department and commences with ten questions, the first three of which will always be pertinent, *viz*. What is to be heat treated? What heat treatments are required? and What quantities will have to be handled?

The appendix contains, *inter alia*, a reprint of DIN.17014, the official German glossary of technical expressions concerning heat treatment, lists of German specifications and of technical leaflets issued by Verlag Stahleisen and a hardness comparison table. The book concludes with 399 classified references and adequate name and subject indexes.—J. F. KAYSER.

SALIN, É. '*La Civilisation Mérovingienne, d'après les Sepultures les Textes et le Laboratoire. Troisième Partie—Les Techniques*'. 10 × 6½ in., pp. 311. Illustrated. 1957, Paris: Éditions A. ex J. Picard et Cie. (Price 2500 Fr.)

This is the third of four volumes which cover one of the most important periods in the development of metalworking in North-west Europe. As the subtitle indicates the treatment is both ambitious and comprehensive. To judge from the present volume it is also entirely successful. The author's efforts over the past decades are well known to workers in this field. Even so it is surprising to see *how* much has been done and

learnt. After stressing the need for even more co-operation between archaeologists and the various scientific disciplines, M. Salin describes work that was carried out on metal artefacts very largely under his direction at the Laboratory of the Musée Lorrain at Nancy. Some 180 spectrographic and metallographic analyses are presented, together with tentative interpretations and general hypotheses, and directly related to the available documentary and archaeological evidence. Due credit is given to the many other specialists who willingly helped the author.

Readers of this *Journal* will find of greatest interest the first half of the book which deals with 'Fers et Aciers'. Inevitably, in the period covered—which has its immediate metallurgical roots in the Roman era and comes to an abrupt end about 1100—that means more or less the study of arms and armour. The thorough treatment given here to the 'pattern-welded' sword (épée damassée) is particularly valuable as the author and his colleague M. France-Lanord first undertook its metallographic examination systematically. It is a pity that the book was at too advanced a stage at the time to include a reference to recent forging work by J. W. Anstee (see *Nature*, 1956, **178**, 29 December, 1432) which showed, among other things, that patterns were produced even by the slag in very pure iron, and did not require alternate strips of 'iron' and 'steel'. The rest of the book describes methods of working copper and its alloys, techniques of onlay and inlay mainly on a ferrous base (in the examination of which, as for pattern-welded swords, radiography has played such an important part), and the production of jewellery chiefly from non-ferrous metals. Full justice is done to the subject as a whole, and the many and varied objects in particular, in the tables and illustrations, although micrographs appear without magnifications, and the standard of scientific treatment is unfortunately not matched by that of book production. An index is promised with the last volume.

Perhaps one of the most telling points is the author's frequent comparison of these ancient materials with relevant modern specifications. It is refreshing to be so convincingly reminded of the incredibly high standards of purity and workmanship achieved some 1500 years ago.—L. Biek.

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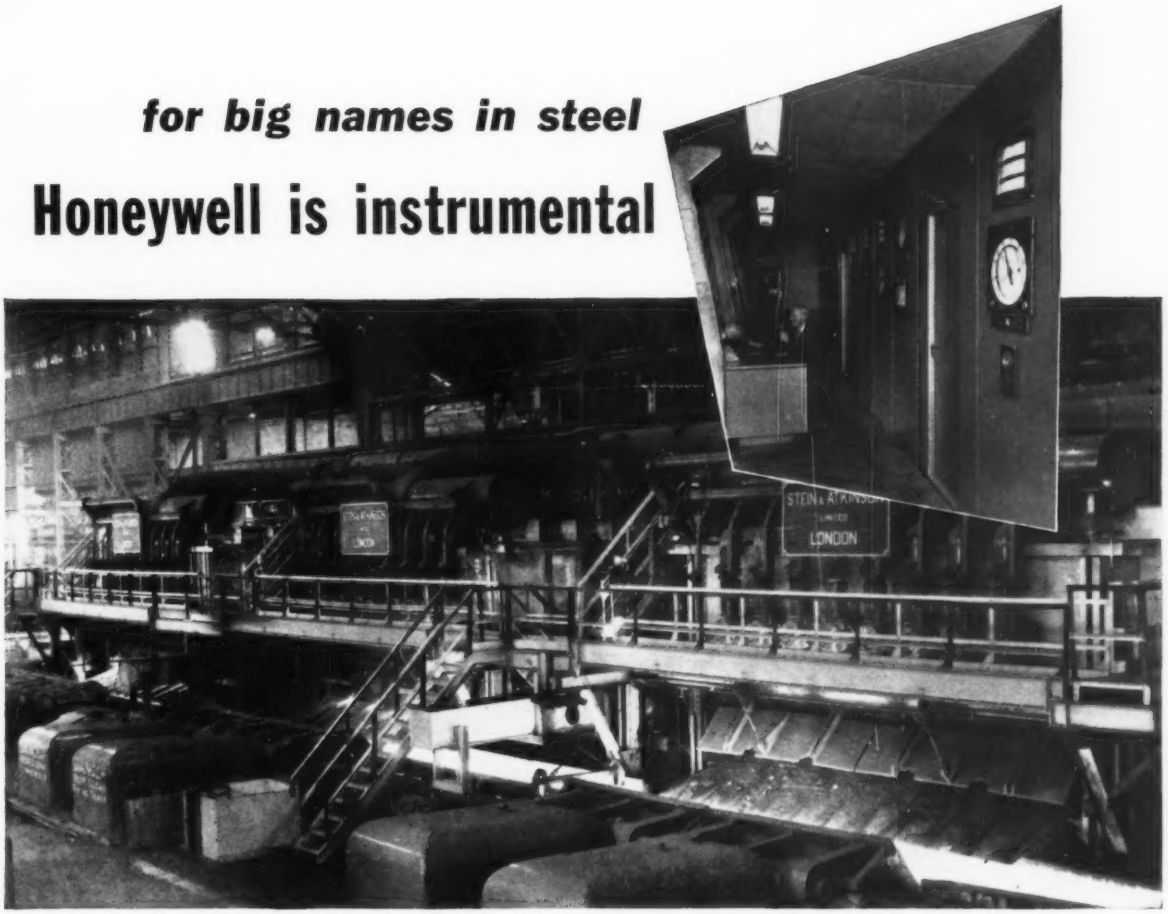

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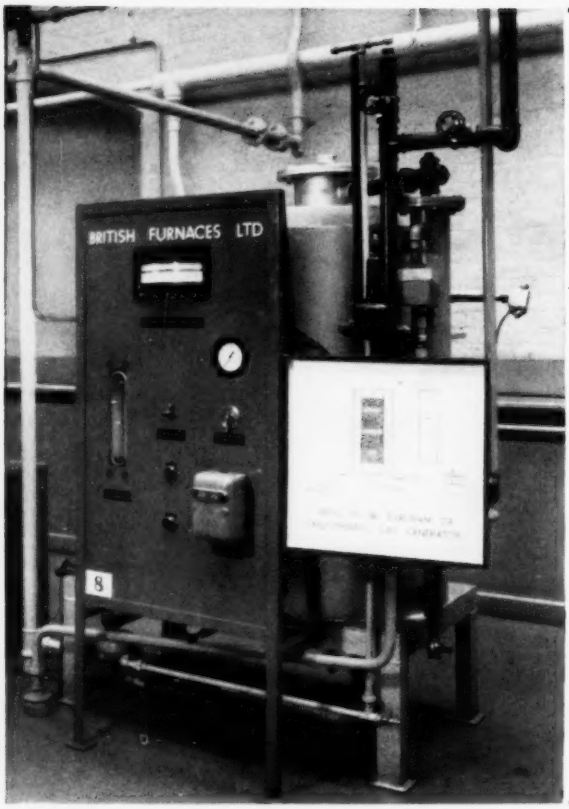

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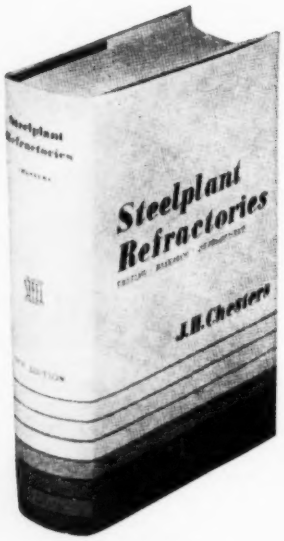

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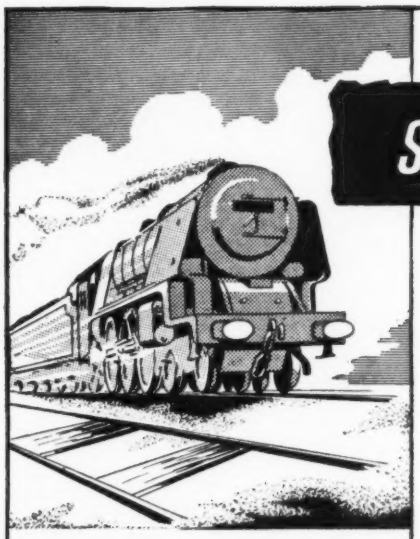

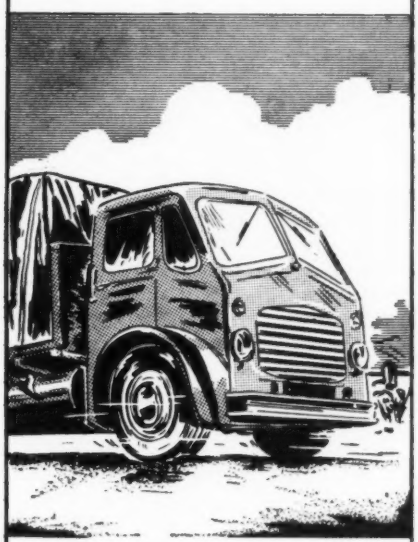

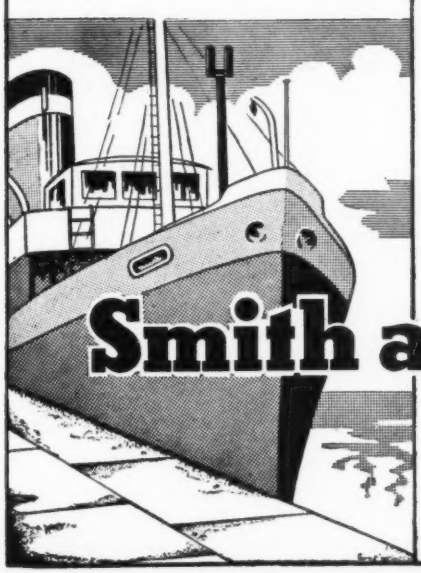

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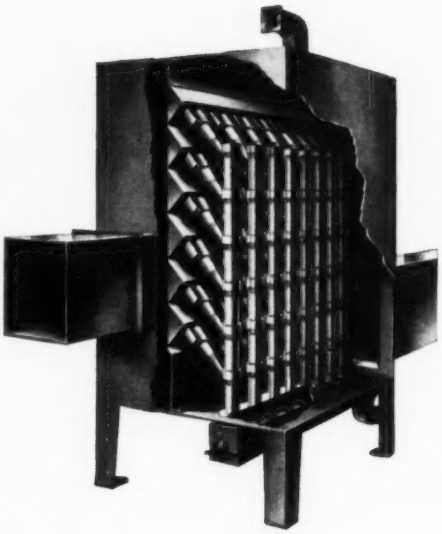

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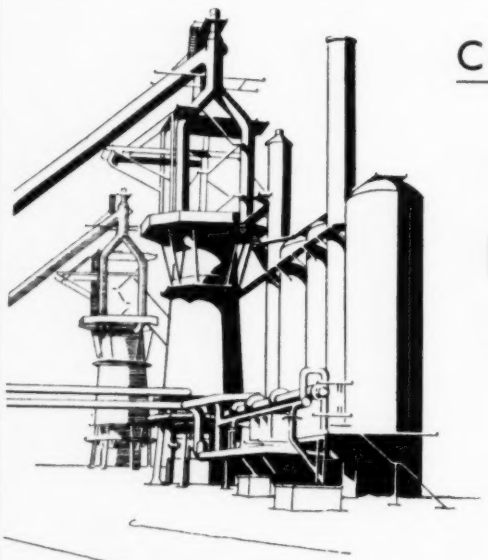

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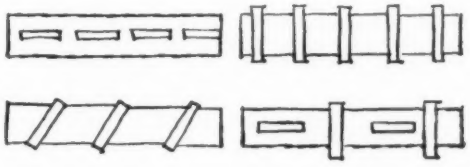
Lighting-2

The general principles of factory lighting have been dealt with in the previous data sheet (No. 6). This one considers briefly certain factors—not always fully appreciated — that influence the lighting for some particular factory applications. The next data sheet will carry the subject further.

Work benches

The most universal application of lighting is to bench work, for there is no branch of manufacturing that does not have its work benches which, of necessity, are used for a great variety of occupations. No single lighting method is suitable for all cases.

The introduction of fluorescent lighting has gone a long way to solving one of the main problems here; for while the high degree of brightness of filament lamps tends to preclude their use for individual lighting owing to the glare, the fluorescent tube with its greater expanse of light source has made localised lighting with a low mounting height more practicable. Moreover, the length of the fluorescent tube puts into the hands of the designer a means of controlling shadows which, together with glare, probably represent the most prolific causes of errors and eye-strain.



With narrow individual benches (not more than 4 ft. wide), there are four basic methods of localised lighting: longitudinal, transverse, diagonal or a combination of longitudinal and transverse. With wider benches it is not advisable to use fittings directly over benches, and fittings should be behind the workers at each edge of the bench. Where particularly high illumination is required, fluorescent fittings may be mounted as local lights—low enough for the skirt of the reflector to conceal the lamps from the eye of the operator.

It is good practice to use reflectors which allow a reasonable amount of light to spill upwards, giving a certain amount of general lighting.

High-bay shops

Probably the most difficult of all factory lighting problems is that of high-bay lighting. In lofty, long and sometimes necessarily dirty shops such as those which house really large machine tools and overhead cranes, which do their worst to defy the efforts of the illuminating engineer, it requires great ingenuity, coupled frequently with high lamp wattage, to provide the workman with enough light to allow him to do his job efficiently. From the planer operator to the slinger, the workman, though he may not know it, is dependent on good lighting if he is to avoid an over-cut or a serious crane mishap.

The major problems associated with the lighting of high and relatively narrow shops, such as heavy machine shops and foundries, are :—

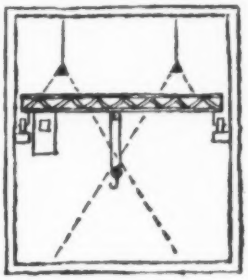
(a) Poor light utilisation caused by excessive light absorption by the large and often dark wall area.

(b) Preponderance of light flux downwards and poor cross lighting causing poor illumination on vertical surfaces, and heavy shadows.

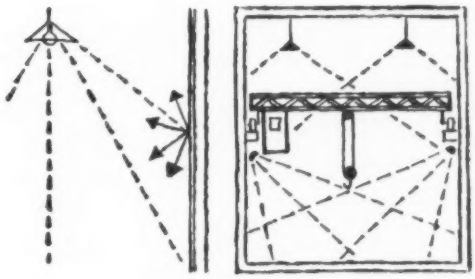
(c) Possibility of heavy light absorption in the atmosphere.

(d) Difficulty of access to high fittings for maintenance.

In high-bay workshops there is a tendency to use concentrating fittings so that the maximum proportion of the light output reaches the working area without spread to the walls, but the saving in wall absorption is obtained only by accepting a depressing environment, poor cross lighting and heavy shadows.



In many cases it is good practice to accept the inevitable reduction in light utilisation by wall absorption and to reduce this by applying light colours to interior surfaces where possible throughout. This approach results in more cheerful conditions and provides equally good illumination values and better cross lighting. Even better is to add angled lighting from the sides below crane level.



In the conditions obtaining in this type of shop, rapid deterioration in light source intensity due to dust must be expected. Facilities should always be provided for easy access to fittings for cleaning and maintenance.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone : TEMple Bar 9434.

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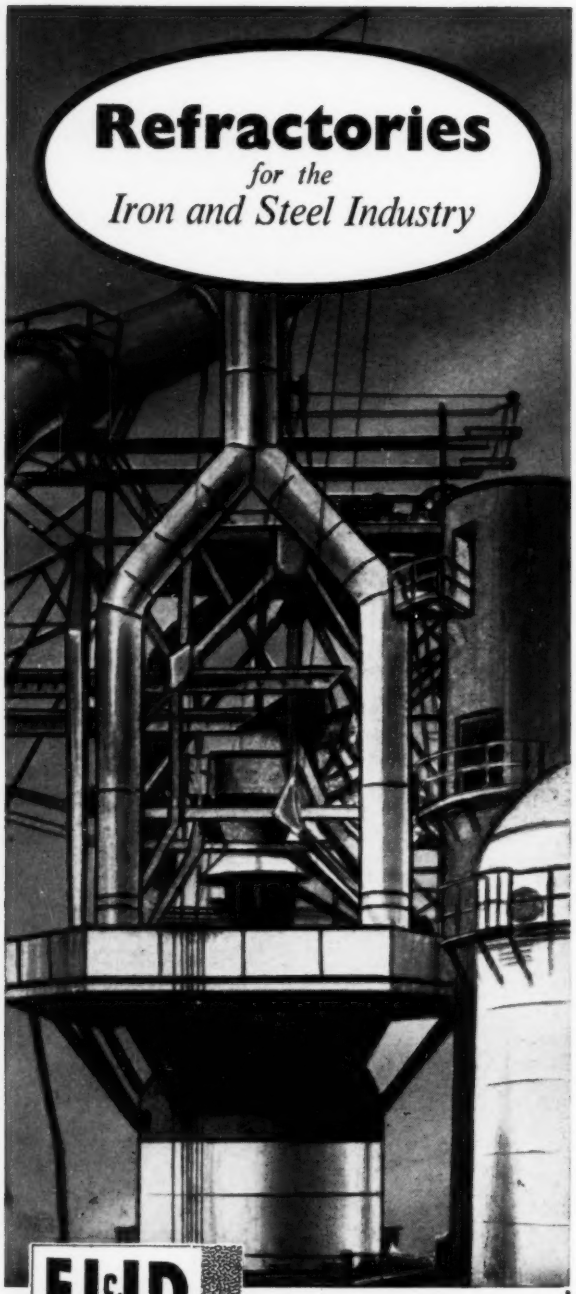

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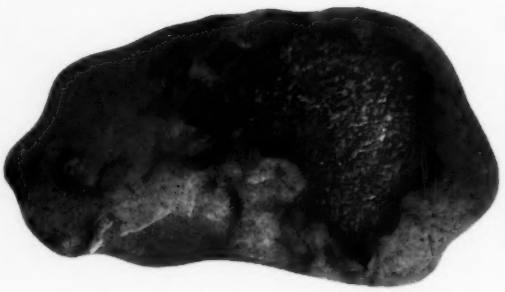

Special Report No. 66

The corrosion of iron and steel costs industry millions of pounds every year, and research on the best ways of saving this money is of the highest importance. The Sixth Report of the Corrosion Committee, which was founded in 1928, has recently appeared as No.66 in the Institute's Special Report series; it contains an account of the researches carried out during the past twenty years.

The Report covers the corrosion of iron and steel in air, in soil, and in water; it details the results of numerous experiments and recommends methods of protection against the many different forms of corrosion. Reports of tests carried out to ascertain the corrosion rates o different kinds of bare irons and steels all over the world, and of steels protected with paint and or metal coatings, are given.

Two other interesting researches described in the Report concern the corrosion and protection of steel at elevated temperatures up to 350°C, and marine corrosion. As a result of the latter, several reliable anti-corrosive compositions have been formulated, some of which are in use on H.M. ships and the 'Queens'.

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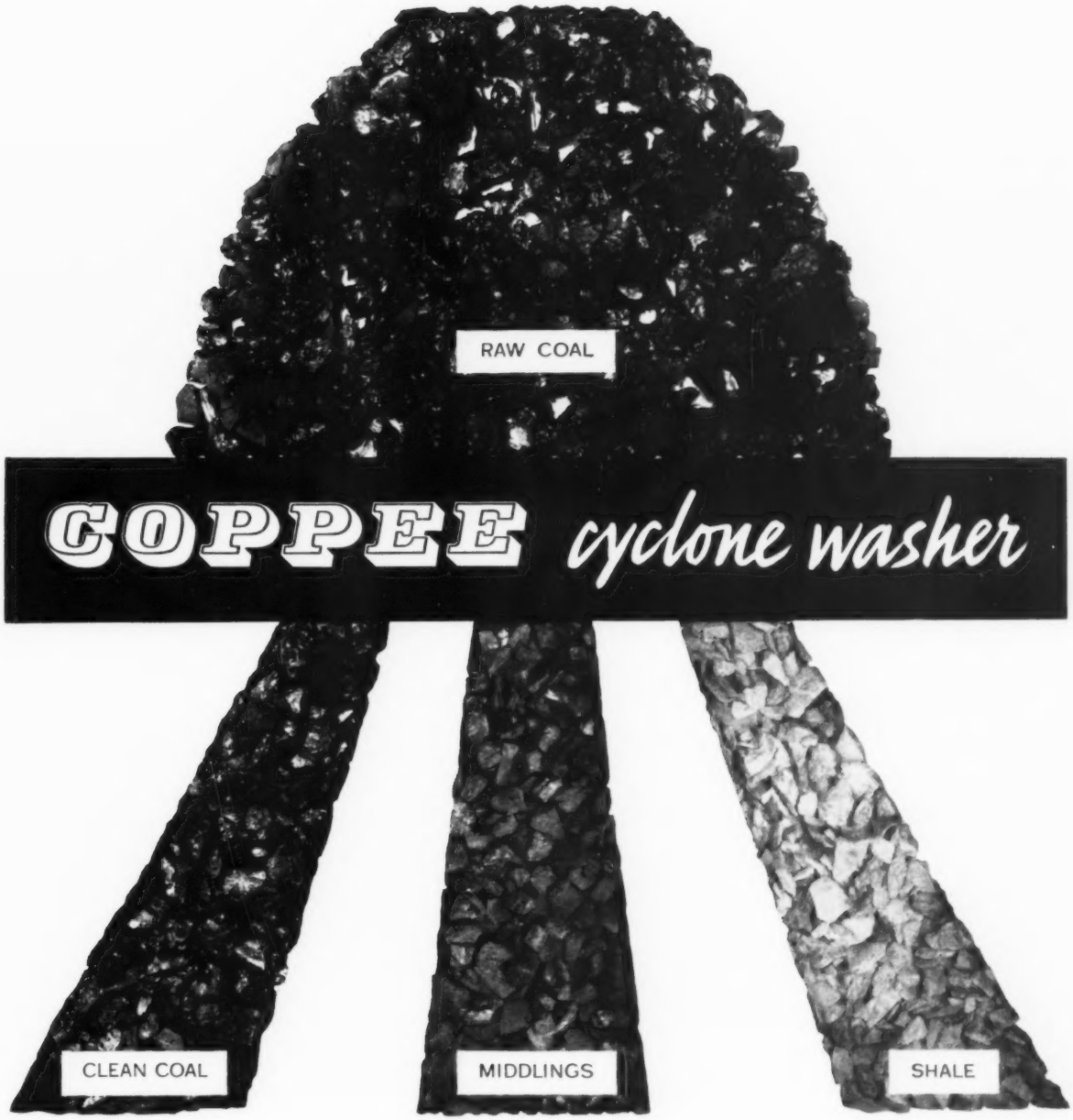

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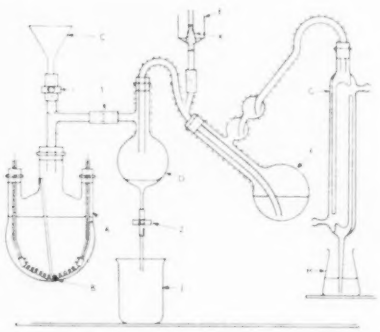
The Determination of Nitrogen in Steel



Great interest has always been shown in the role of nitrogen in determining the properties of ferrous alloys. Reliable and accurate methods are therefore necessary for determining the content of this element in alloys.

The establishment of the reproducibility and accuracy of analytical methods to serve as routine or reference procedures for the many alloys now produced is a major undertaking. It was for this reason that the Nitrogen Group of the Steelmaking Division of the British Iron and Steel Research Association was set up eight years ago. The Report of the Group has now been published as No. 62 in The Iron and Steel Institute's Special Report Series. The information it contains will be of inestimable value to all those interested in this subject.

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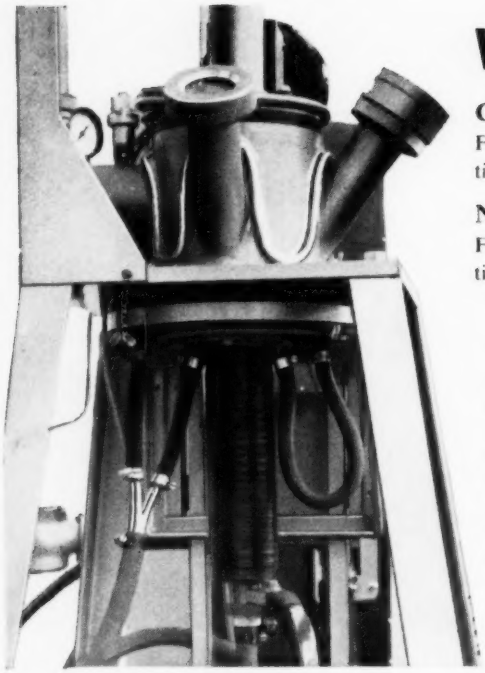

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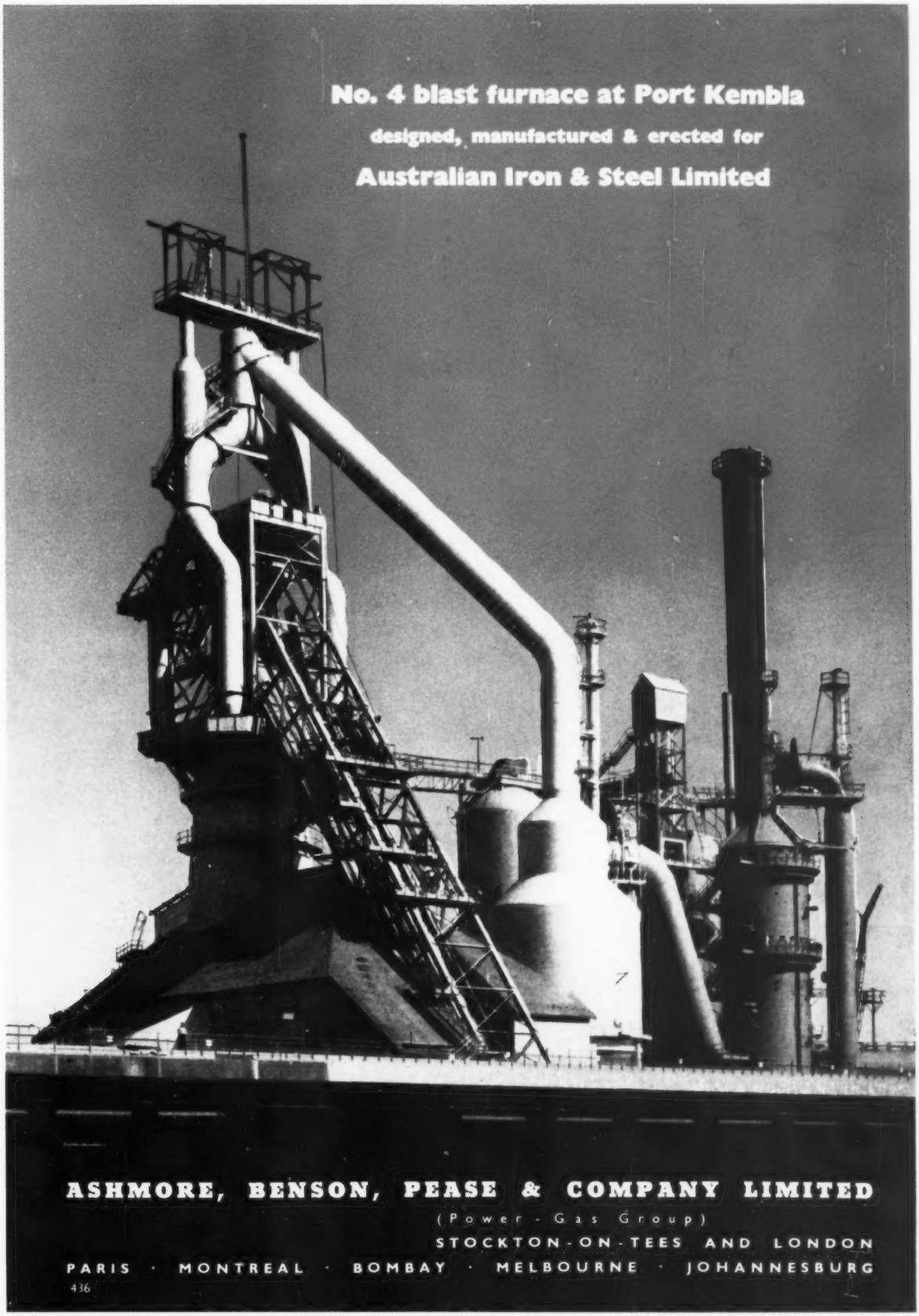
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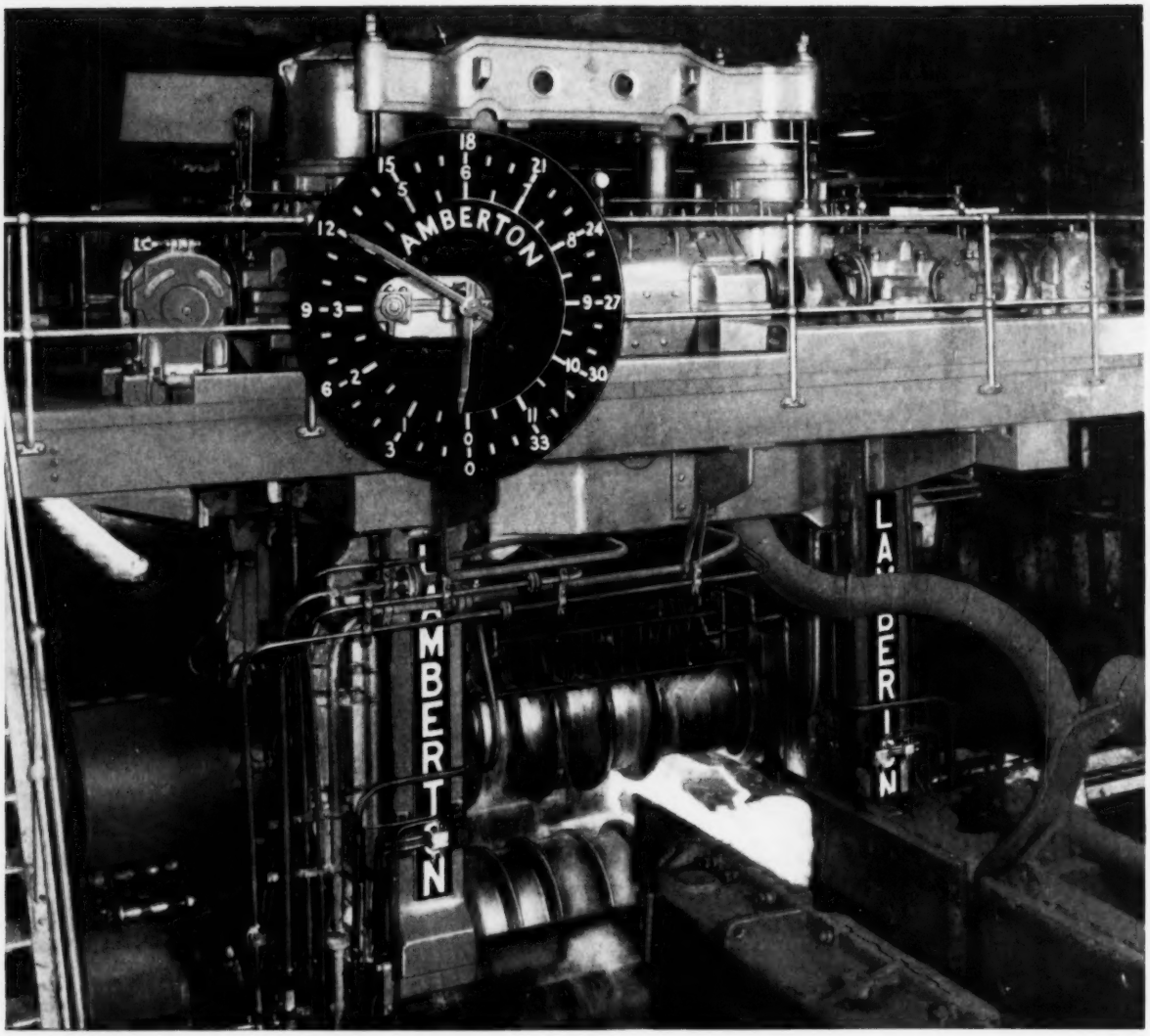

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